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3 A Summary of Current Program 4/1/67

and Preliminary Report of Progress

for 4/1/66 to 3/31/67

SOIL AND WATER CONSERVATION

RESEARCH DIVISION

of the

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

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This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between April 1, 1966, and March 31, 1967. Current agricultural research findings are also published in the monthly USDA publication, Agricultural Research. This progress report was compiled in the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D. C.

July 1, 1967



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## INTRODUCTION

Our burgeoning population and complex technology are exerting ever-increasing demands on our soil and water resources. Conservation of these vital resources from which man draws his sustenance is imperative. Conservation is rooted in the principle that a resource must not be used faster than it can replace itself. Yet, in some areas, we are ignoring this principle. Aquifers that have been built up over centuries by Nature are being depleted in decades by man. Fertile soil formed during glacial ages is allowed to gully and erode. Rivers that originate from deep springs or snow-capped mountains are fouled with the sewage and effluent from our cities and industries and the erosion-produced sediment from agriculture and construction.

Research-derived management practices have done much to alleviate problems of the past. The Soil Conservation Service, the Bureau of Reclamation and other action agencies have instituted effective technological programs based on these practices. Watershed associations, Soil and Water Conservation Districts, the National Reclamation Association, Irrigation and Drainage Districts and similar resource-using organizations are actively supporting the advance of research-based technology.

Today we are world leaders in soil and water conservation. However, world food developments and changing pressures in agriculture in relation to alternative uses of our resources demand renewed vigor in our research efforts. We are being called upon to help develop worldwide soil and water programs.

The primary objectives of the Soil and Water Conservation Research Division are: (1) To develop efficient management practices for conservation and use of soil resources that will assure an adequate sustained yield of high-quality food and fiber; (2) To gain an understanding of the complex interrelationships of weather, soil, vegetation, topography, geology, and other factors in the environmental ecology as they affect soil and water resources and management practices; (3) To develop more efficient methods for collecting, storing, conveying, and using water resources, and to devise ways of reclaiming wasted or contaminated water for reuse; (4) To develop improved techniques and structures for upstream flood prevention and watershed protection including methods for controlling erosion and sedimentation; (5) To develop improved irrigation and drainage systems involving more economical and effective methods and materials; (6) To evaluate the severity and extent of soil, water, and air pollution, and to provide alternatives or remedial measures, where necessary, to alleviate this pollution.

### Selected Examples of Accomplishments - 1967

#### 1. Anaerobic Soil Bacteria Reduce DDT Persistence.

Micro-organisms that live without air--anaerobic bacteria--can provide a way of reducing the accumulation of the persistent chlorinated insecticide DDT in soils. The principle of anaerobic decomposition has been applied for many years in septic tank design. The indication that it can be applied to

reduce the persistence of DDT is of great public interest. At Fort Collins, Colorado, soil samples treated with DDT were incubated for 4 weeks to promote the growth of anaerobic bacteria. Less than one-half of the applied DDT remained in its original form at the end of incubation. In sterilized soil samples also incubated, all of the DDT remained intact throughout the 4-week test period. Since the soil contains the organisms required for DDT degradation, practical methods should be possible for ridding soils and sediments of persistent insecticides that may contaminate the environment.

## 2. Laser-beam Automatic Grade Control System Speeds Accurate Installation of Subsurface Drains.

An accurate grade control system for both conventional and high-speed drainage equipment has been developed and tested at Columbus, Ohio. This system utilizes a portable, but stationary, low-power laser beam as an elevation reference and an electronic, machine-mounted detector device which automatically operates the hydraulic depth-regulation mechanism. In field trials, satisfactory depth regulation was achieved which corrected all vertical deviations greater than  $3/8$  inch from the desired drain grade. Tests have been made for distances of up to 1,500 feet, but comparable control is anticipated over even greater distances. This control system, in combination with newly developed corrugated plastic pipe, now makes it possible to rapidly and accurately install subsurface drains at greatly reduced costs. The system will have further application in agriculture for land leveling, ditch construction, terracing, etc. It can also be applied to civil engineering and military construction projects to speed up operations and minimize labor and other costs where grade control of earthmoving equipment is required.

## 3. Water Stress Changes the Nutritional Quality of Plants.

Water stress in plants appears to cause striking changes in the nutritional value of the plant proteins and amino acids for human and monogastric animals. The breakdown of proteins into amino acids and the further breakdown of amino acids to carbon dioxide, ammonia, and water was accelerated by water stress. In water stress studies conducted at the U.S. Plant, Soil, and Nutrition Laboratory, Ithaca, New York, the amino acids, glycine, glutamine, histidine, and leucine were degraded rapidly, whereas valine, phenylalanine, arginine, and serine were degraded slowly. Proline behaved differently in that substantial amounts were synthesized during wilting and the process continued as long as there were sugars available. These findings suggest that forage quality might be largely determined by water management practices. Studies will be made under field situations to determine the degree of water stress required before protein breakdown occurs.

## 4. Monthly Wind Erosion Climatic Factor Reduces Error in Designing Wind Erosion Control Practices.

At Manhattan, Kansas, computation of a monthly wind erosion climatic factor for 187 locations in the most severe wind erosion areas in the United States has shown that the potential erosiveness, or conversely the requirements for

wind erosion control for a given field, vary during the year even though soil, residue, and roughness conditions remain constant. The climatic factor, which is used in the wind erosion equation and evaluates the influence of wind velocity and surface soil moisture on amount of erosion, was found to have a range of values throughout the year that varied considerably from the annual value. Midland, Texas, for example, has a climatic factor of 100 in March and 60 in October, but has an annual value of 80. Use of the monthly factor instead of the annual factor in the wind erosion equation will greatly reduce errors in estimating erosion conditions and in designing effective control practices.

#### 5. Reservoir Storage Depletion Rates.

Studies of data on sedimentation for 968 reservoirs in the United States reveal high rates in the smaller reservoirs. A measured 3 percent average annual reservoir storage depletion rate in the smaller impoundments of the United States seems excessive. About 20 percent of the reservoirs studied will be half filled with sediment in about 30 years, if historical rates persist. The overall, average depletion rate of 0.2 percent of total reservoir capacity is less alarming. Depletion rates generally decrease as reservoir capacity and watershed size increase. The findings tend to emphasize the need for persistent efforts in erosion control, for the development of new erosion control methods, and for studies of the designs of sediment interceptor structures and sediment bypass systems.

#### 6. Nitrate and Other Water Pollutants Under Fields and Feedlots.

Water samples from beneath fields and feedlots in the South Platte River Valley of Colorado contain variable amounts of nitrates, carbon and ammonia. The distribution of nitrates, highly toxic to infants, and other pollutants were measured under fields and feedlots. Analyses of cores obtained in intensive core-drilling operations showed that the average amount of nitrate moving through soil profiles toward the ground water varied widely with land use. Average amounts in pounds of nitrate nitrogen per acre to a depth of 20 feet were: Irrigated alfalfa fields, 79; native grassland, 90; cultivated dryland, 261; irrigated fields not in alfalfa, 506; and cattle feedlots, 1436. Although much larger amounts of nitrate are present under feedlots per unit area, irrigated fields probably contribute more total nitrate to the ground water because of larger acreage. Data indicate that 25 pounds of nitrogen per acre are lost annually to the water table from irrigated fields. Contrary to a common belief that the soil microbial population decreased to uniformly low numbers below the root zone, marked variation in microbial populations, with some surprisingly high, were noted in the deeper profile. At many sites, there appeared to be a higher microbial population at or just immediately above the ground water table.

#### 7. Plantain and Yam Yields Greatly Affected by Planting Practice.

Yields of well-fertilized plantains and yam tubers were increased by as much as 60 percent by increasing the plant population and modifying the planting pattern in Puerto Rico. Increasing the population of plantains

from the conventional 600 plants per acre in an 8-foot by 10-foot pattern to 1450 plants in a 5-foot by 6-foot pattern increased the yield from 8 to 13 tons per acre with no appreciable effect on size of fruit or bunch. Planting staked yams on beds at 2-foot intervals rather than the standard 4-foot intervals increased tuber yields by 50 percent. These data show that these two major food crops in the food-deficient humid tropics areas can be increased substantially by a low-cost revision in agronomic practice.

#### 8. Scheduling irrigations using crop and climatic parameters.

Scheduling irrigations for maximum water-use efficiency, optimum yields and low labor input has been a problem faced by the irrigation farmer for years. Studies conducted at Twin Falls, Idaho, in 1966 indicate that all irrigations throughout the season can be scheduled using climatological data, precipitation, and stage of growth characteristics of the crop. The yield of sugar beets, nearly 25 tons per acre, on a treatment where all irrigations were based on climatological data was not significantly different than those from two other treatments that were irrigated according to prescribed soil moisture levels, a method requiring equipment and time not readily available to the irrigator. This study is being expanded to other crops and to farm fields with cooperators irrigating according to predicted water requirements. Irrigation scheduling will also involve utilizing 3- to 5-day forecasts of climatological conditions, thus permitting the scheduling of irrigations 3 to 5 days in advance.

#### 9. Improving prediction of sediment load.

An improved method is being developed for predicting sediment load in ephemeral, arid-region streams. The "sediment rating curve" commonly used for estimating sediment, on the basis of streamflow alone, gives unreliable estimates for small southwestern streams. However, analyses of sediment samples collected in summer thunderstorm flows on the Walnut Gulch Experimental Watershed, at Tombstone, Arizona, show that deviations from a mean rating curve are related to parameters of the convective storm causing the flow, and to the antecedent flow. Major determinants of the sediment load at a particular channel station, in addition to the streamflow rate, are indicated to be: (1) distance from the storm center, (2) erodibility of watershed portion covered by the storm, (3) time since last previous flow, and (4) elapsed time since beginning of the current flow.

#### 10. New method speeds leaching of salts.

Irrigation practices put into effect while growing a cotton crop have resulted in removing more than 16 tons of salt per acre at the Drainage Research Farm at Brawley, California. This quantity of salt removed in one year is 30 percent of the amount initially present in the 0- to 6-foot soil profile. The irrigation practice of using the drain tile systems to help saturate the soil profile and dissolve more soil salts has worked well at this location where good horizontal but poor vertical water movement characterizes the soil profile. This suggests a new technique for more

effective irrigation of the soil profile and more efficient leaching of mineral salts.

11. Quality of Coastal Bermudagrass can be improved by management.

Studies at Watkinsville, Georgia, concerned with the quality of large acreages of Coastal Bermudagrass in the Southeast indicate that the upper half of the sward is more digestible, but the lower half has a greater nutrient content. In vitro determinations and chemical composition studies indicated that increased digestibility is associated with low lignin in the stems and low fiber content throughout the plant. Digestibility of the forage increased with the fertility level. The low magnesium content of some forages was easily corrected by adding adequate lime to the soil. The crop management aspects of these studies indicated that the digestibility of Coastal Bermudagrass might be increased by fertilizing and clipping the crop at a higher level.

12. Soil survey and photogrammetry greatly improve hydrograph synthesis.

Soils and land slopes are grouped to provide relatively homogeneous areas of infiltration, and overland and channel flows of watershed runoff are now successively simulated in the U.S. Hydrograph Laboratory. Rainfall in excess of infiltration on each soil-slope zone is routed through overland flow, with hydraulic geometry synthesized from the geomorphic properties of the upland area. Flow geometry for the channel system is synthesized from stream and valley cross-sectional data obtained by photogrammetry. This sequential procedure allows rational examination of the effects of watershed properties of runoff hydrographs.

13. Methods of revegetating strip-mined areas in Georgia.

Methods for revegetating areas left barren by kaolin strip mining in Georgia have been developed by the Southern Piedmont Conservation Research Center at Watkinsville, Georgia. When lime and nitrogen and phosphorus fertilizer were added to bahia and Coastal Bermudagrass, excellent growth was obtained. These studies mark the first attempts to reclaim clay pit spoils, which could include more than 1 million acres in Georgia alone.

14. New device prevents siltation of subsurface drains.

Sedimentation is a major cause for failure of subsurface drains. With present sediment-filtering methods, particles accumulate and reduce, or in some cases even prevent, water entry into the drains. At Columbus, Ohio a simple anti-sedimentation device has been developed that effectively excludes sediment from subsurface drains. The new nonfiltering device is based upon the principle of velocity control in relation to soil particle size in an upward flow channel. This channel is the path by which water flows from the soil into the drain. It provides for separation and discharge of the water from the soil by requiring that the water flow upward at a low velocity through a vertical section before entering the

drain. The sediment does not rise and so does not enter the drain with the water. Velocity control is obtained by proper design of the position, shape, and cross-sectional area of the upflow channel. For future drain installations, this device could eliminate the age-old problem of drain failures caused by sedimentation.

#### 15. Channel stability can be predicted from simple measurements.

A field study of stability of channels in the Kansas and Nebraska Loess-Drift Hills disclosed that such channels behave predictably. Regression analysis of data obtained from channels in the 9.17-square-mile Sabetha Lake Watershed near Sabetha, Kansas, shows that the erosion or deposition in acre-feet per hundred feet of incised channel per year is correlated ( $\bar{R} = 0.92$ ) with the hydraulic radius per foot of stage and the watershed drainage area--two easily measured physical quantities. Prediction equations such as those developed in this study are useful in the design of stable channels in small watershed projects and in predicting possible changes in channels when some change is made in the flow regime.

### EXAMPLES OF RECENT ACCOMPLISHMENTS OF THE STATE AGRICULTURAL EXPERIMENT STATIONS

#### 1. Wind Erosion Control

Wind erosion is becoming an increasingly serious problem on the sandy soils of northwestern Ohio. Scientists at the Ohio Agricultural Research and Development Center indicate that the increase results from the combined effects of larger field size, intensive row crop production, elimination of small woodlots and natural windbreaks, fall and early spring plowing, and less ground cover because of better weed control. One effective control practice is the planting of row crops under a no-tillage system which leaves a protective cover on the soil surface. In one severe wind storm up to 130 tons of sand per acre was moved from land in corn under conventional plowing compared to only 2 tons per acre from the no-tillage area. Average corn yields the past 2 years have been 93 bushels from the no-tillage area compared to 68 bushels per acre from plowed land. Other effective wind erosion control practices include strip cropping, planting in sod or small grain crops, permanent windbreaks, tilling and planting at right angles to prevailing wind direction and reduced tillage intensity.

#### 2. Low-gallonage Sprinklers for Cranberry Bogs

Research at the Massachusetts Cranberry Experiment Station has shown: (1) that solid-set low-gallonage sprinkler systems utilizing plastic tubing can be designed and installed for about \$500/acre--having a life-expectancy of at least ten years and producing values that amortize costs in three years; (2) that these systems provide full frost protection while requiring only 10% of the water formerly needed for flood frost protection; (3) that they provide ideal irrigation as needed during summer dry spells, avoiding the serious hazards and water-loss of growing-season irrigation floods; and (4) that they can distribute insecticides and fungicides with precision timing and strict area control without the drift and environmental

contamination of aircraft-applied dusts and mists.

### 3. Critical Period of Water Need

At the New Jersey Agricultural Experiment Station, in cooperation with ARS, the most critical period of water need by peppers was found to be the time of initial flowering and early fruit set. High soil water and atmospheric stress during this period can reduce early and final yield 50%. The effects of high water stress during this 3-week period were not modified by providing adequate available water either before or after this stage of growth. High stress from planting to initial flowering did not adversely affect yield.

Similar information is being, or has been, obtained for the major vegetable crops of the region. Information from this research will make for more efficient use of limited irrigation water supplies.

### 4. Gaseous Loss of Nitrogen from Soils

Nitrogen compounds in agricultural soils will eventually pass through ammonium and usually nitrite and nitrate forms. The nitrates and nitrites may be denitrified by biological or physical chemical processes, depending upon the environment.

The critical role of nitrite nitrogen as the key intermediate in the loss of nitrogen from soil has been clearly demonstrated by researchers at the California, Oregon, and Utah Agricultural Experiment Stations as part of Western regional project W-85, Nitrogen Transformations in Western Soils. Results this year showed that both biological and chemical routes of nitrogen loss, exclusive of ammonia volatilization, pass through the nitrite form. Decomposition of nitrite to nitric and nitrous oxides was markedly pH dependent with little loss occurring above pH 6.3. In like manner, under aerobic and acid conditions considerable nitrite is converted to nitrate by non-biological pathways. Of special significance was the definitive information obtained that some nitrogen gas ( $N_2$ ) is produced as an end product of non-biological nitrate decomposition in either aerobic or anaerobic systems. Mass spectrometer analysis of gases evolved during decomposition of nitrous acid in soil and in humic acid preparations showed  $N_2$ , NO, and  $N_2O$  to be evolved at low pH values, whereas at only slightly acid pH values,  $N_2$  was the principal gas evolved.

This research is providing an understanding of the contribution of biological and chemical nitrite decomposition to loss of applied nitrogen and potential contribution of nitrogen oxides to atmospheric pollution.

### 5. Effect of Sulfur on Crop Yields

Work at the Minnesota Agricultural Experiment Station has shown that soils in north-central and northeastern Minnesota are generally low in available sulfur. Field experiments in the Park Rapids area have shown that plots treated with sulfur applied either as gypsum or elemental sulfur have generally shown a doubling of alfalfa yields with some cases of as much as

a three-fold increase. Treatments of 100 pounds of elemental sulfur or 1,000 pounds of gypsum per acre in 1962 continued to maintain alfalfa yields near maximum levels during 1966. Studies of small grain responses to sulfur applications in this area showed that barley yields increased 4 to 11 bushels, oat yields 4 to 8 bushels and wheat yields 2 to 6 bushels per acre over the untreated plots. Corn and potatoes did not show yield responses to sulfur applications in the area.

#### 6. Zinc Toxicity to Cotton

Cotton, soybeans, and peach trees will not grow normally on Coastal Plain soils of South Carolina from which old peach trees have been removed the previous year. Only in localized areas within orchard sites where peach trees have been piled and burned and the ashes incorporated into the soil will cotton grow normally. Soils in these localized areas have a higher pH (around 7.0) and a higher level of bases than the remainder of the orchard site.

At the South Carolina Agricultural Experiment Station cotton grown in pot cultures of Faceville sand (pH 5.3) from a peach orchard site showed stunted growth, leaf chlorosis, and high concentrations of zinc and manganese. Raising soil pH to 6.0 or above with calcium carbonate + magnesium carbonate, peach tree ash, or sodium carbonate produced normal growth and decreased concentrations of zinc and manganese in cotton plants.

Lowering the pH of Eustis sand, which had never been in peaches, to 5.0 had no effect on growth of cotton. Adding an amount of zinc much below that sprayed on peach trees during the life of an orchard produced stunted growth and chlorotic leaves.

Stunted growth of cotton following peaches appeared to be caused largely by zinc spray residues made available by low soil pH.

#### 7. Movement of Aldrin and Parathion in Soils

Laboratory experiments on adsorption, desorption, and leaching of parathion were conducted at the Texas Agricultural Experiment Station. Eight soils of diverse properties--pH 5.0 to 8.2, organic matter 0.4 to 4.4%, and cation exchange capacity 8 to 63 meq per 100 grams--were employed.

Parathion was found to be relatively immobile in the soils studied. Calculations indicated that approximately 800 inches of rain would be needed to leach parathion to a depth of 60 inches in Willacy fine sandy loam; 1710 inches would be needed with Houston clay.

Related studies were made with aldrin using four soils, two clays and Ottawa sand. Aldrin was adsorbed to about the same extent by kaolinite and montmorillonite. In soils, retention of aldrin was more nearly related to organic matter and clay percentage than to clay type.

The information gained shows that neither parathion nor aldrin is a threat to ground water in any of the Texas soils used. Since the soils used

represent a wide range of properties common to the West and South, it is unlikely that movement of either insecticide to ground water through any soil of the area is of practical importance.

#### 8. Prevention of Hypomagnesemia

Hypomagnesemia in cows grazing spring pasture is seen in many areas of the United States. West Virginia workers have shown that by feeding MgO in compressed blocks made of a mixture of liquid and dehydrated molasses the blood magnesium levels are increased. Previous work has shown that daily drenching or injections of MgO will prevent hypomagnesemia. This West Virginia work will lead to improved practical prevention methods.



## AREA 1: SEDIMENTATION PROCESSES IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

Problem: Most sediment problems are associated with unwanted deposition of eroded material in reservoirs, harbors, stream channels, streets and highways, or on floodplain lands. In addition to these deposition problems, sediment in streams damages fish and wildlife and it must be removed from domestic and industrial water supplies. Sediment in transport, the imbalance of the sediment load in streamflow because of alterations or impoundments in channel systems, and even erosion control practices in tributary watersheds, can also create major sediment problems. In many parts of the country, abatement of sediment damages is one of the primary justifications for watershed protection and development programs.

The processes of sedimentation are complex, but an understanding of these processes and the factors controlling them is essential for the development of practices and programs for solution of sediment problems. The relation between sediment load, streamflow, land use and watershed characteristics must be clarified through research. Improved criteria are also needed for computing the bedload movement of sand, gravel and other coarse debris; for predicting the rates of silting, the sediment trap efficiency, and the distribution of sediment in floodwater detention reservoirs; and for describing the morphology of stream channel systems having beds and banks of alluvial or cohesive soil materials.

This research seeks new and improved criteria for evaluating various sedimentation processes, for identifying sediment sources, and for developing methods for sediment control and stream channel stabilization.

### USDA AND COOPERATIVE PROGRAM

The Division carries on a continuing long-term program of both basic and applied studies of sedimentation processes, involving hydraulic and agricultural engineers, soil scientists, soil physicists, geologists, chemists, and botanists, for the purpose of developing and proving new information useful in the solution of various sediment and stream channel problems. Intensive research in all aspects of sedimentation is carried out at the USDA Sedimentation Laboratory, Oxford, Mississippi, where more than one-half of the Division's sedimentation research personnel are headquartered. At other locations, attention generally can be given only to the most critical problem of the region.

All of the studies are cooperative with the respective State Agricultural Experiment Stations. In addition, cooperation is maintained with The Illinois State Water Survey Division, The University of Mississippi, The Oklahoma State University, and The University of Oklahoma Research Institute.

A total of 21.21 scientific man-years was devoted to this research in the 1966 reporting period. Of this number, 12.12 man-years were devoted to studies of sediment sources and yields from agricultural watersheds; 1.73 to rates and processes of reservoir silting; 3.57 to mechanics of sediment entrainment, transportation and deposition; 2.79 to stream channel morphology and means and measures for channel stabilization; and 1.00 to valley sedimentation rates and distribution.

#### PROGRAM OF STATE EXPERIMENT STATIONS

A total of 2 scientific man-years is devoted to this area of research.

#### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

##### A. Sediment Sources and Yields from Agricultural Watersheds

1. Sediment sources. A long-term study of three critical sediment source areas on Piedmont soils near Cartersville, Georgia, is near termination. Preliminary conclusions indicate natural vegetation will eventually control erosion unaided on certain of these areas. On others, special treatments, including fertilization, will be required. One prime difference appears to be soil type. Based on a 5-year period (1961-65), the following amounts of rainfall, with computed EI values, were required to remove soil at the rate of 1 ton/acre/year for comparable slopes:

<u>Soil</u>	<u>Average Rainfall</u>	<u>EI</u>
Madison gravelly clay loam	0.73 in.	568
Wilkes stony sandy loam	2.44 in.	1,374
Talladega gravelly fine sandy clay loam	3.65 in.	1,971

Critical areas are a major source of sediment from small agricultural watersheds. Their treatment requires special attention and extra cost in watershed protection and flood prevention programs. Findings that associate soils with treatment needs are valuable in planning for such programs. (SWC 1-b1)

Calibration curves obtained with a Grenada silt loam (0.7 percent O.M.) for neutron probes of Nuclear-Chicago and Troxler Laboratories manufacture, as well as for one constructed in the USDA Sedimentation Laboratory, Oxford, Mississippi, were unaffected by changes in dry bulk density from 1.2 to 1.4 g./cc. Calculations indicate an organic matter content in excess of 0.01 g./cc. is necessary before such changes in dry bulk density will significantly affect the observed slow neutron flux density. (SWC 1-bE1)

Calibration curves for any neutron soil moisture probe can be easily, readily, and reproducibly simulated by using a system of water and slow neutron absorption rods. The latter function as a "sink" for thermal neutrons. Such a system, developed at the USDA Sedimentation Laboratory, Oxford, Mississippi, is homogeneous and lends itself to studies of other factors, such as the effect of elements with high thermal neutron absorption cross sections, influencing neutron flux densities. To convert such a calibration curve to use for a particular neutron probe in a particular soil, it is necessary to make only two measurements in the soil at known moisture conditions. The entire soil moisture-count rate curve is then fitted to the two points. Any variations in instrument performance with time can be readily determined. (SWC 1-bE1)

Measured median raindrop diameters varied from 1.5 mm. at a rainfall intensity of 0.04 inch/hour to 3.0 mm. at a rain intensity of 3.00 inches/hour in natural rain samples procured by the USDA Sedimentation Laboratory, Oxford, Mississippi. These median drop sizes at the indicated intensities correspond closely to those reported by Laws and Parsons in 1943 for rainfall at Washington, D. C. The latter reported 1.25 mm. and 2.75 mm., respectively. Additional measurements of raindrop sizes in natural rainfall of differing intensities have become important because certain drop size-rain intensity-soil erosion associations are utilized in the computations of sediment production. Hudson's more recently published data on raindrop sizes in Rhodesia are in conflict with the previously accepted relationship. (SWC 1-bE1)

Sediment from hill land of the North Appalachian area--a source of pollution to streams and reservoirs--has been greatly reduced by crop rotation and contour strip cropping. The effect of continuous corn on sediment from watershed land of Muskingum silt loam of 9.4 percent land slope was studied at Coshocton, Ohio. Competitive vegetation was killed by herbicides. Manure was applied to the land surface, the customary practice in this region. As there were no tillage operations, the manure and dead vegetation provided a mulch which served as an effective deterrent to soil erosion. In 3 years of study--years of few erosive storms--soil loss from a continuous corn, no-tillage watershed totaled 120 pounds per acre. That from a conventionally tilled watershed was 5,820. Continuous corn farming appears to be practical on hill land with very little erosion hazard providing the land is not tilled, weeds are killed with chemicals, and a mulch is provided. (SWC 1-c1)

Investigations by the North Central Watershed Research Center, Columbia, Missouri, showed that sheet erosion was the major source of sediment in streams flowing from the Iowa and Missouri Deep Loess Hills Land Resource Area. Although active gully headcuts are the major source of large quantities of sediment, they contributed only 20 percent of the total sediment coming from 74- to 83-acre watersheds in contoured continuous corn near Treynor, Iowa. This relationship appeared to be independent of the amount of sediment. In 1966, sediment from the deep gully was 134 tons or 19 percent of the total watershed sediment. In 1965, it was 906 tons or 22 percent of the total. Sheet and gully erosion sediment sources from a 150-acre level-terraced watershed contributed very little to the sediment in the stream. In 1966, total sediment from the gully was only 14 tons, compared to a total of 107 tons from the entire area. These results stress the importance of sheet erosion control measures on cropland for reducing sediment yields in this Land Resource Area. (SWC 1-cl)

Three unit-source watersheds, near Capitan, New Mexico, were instrumented during the year for studying sediment sources. They are on the New Mexico Agricultural Experiment Station's new experimental range, formerly the Fort Stanton tract, where grazing has been excluded for many years and grass cover is good. Sediment production is now being measured, by the Southwest Watershed Research Center, Tucson, Arizona, from 23 unit-source watersheds in Arizona and New Mexico, representing a wide array of rangeland soil and cover conditions. In eleven cases, the total yield is accumulated and measured as deposition in stock tanks (ponds). Suspended sediment is being sampled in the runoff at flow-measuring weirs on the other 12 watersheds. (SWC 1-gl)

2. Sediment yields. At Hastings, Nebraska, total sediment yield data were obtained for two complex watersheds of approximately 400 acres and for a 4-acre unit-source watershed. Random sediment sampling was carried out at two other watersheds (2,868 and 3,490 acres). Runoff from all stations was very small and sediment yields of the two complex watersheds were the lowest since records began in 1957. A radioisotope gage to measure suspended sediment concentration was installed on one of the complex watersheds. However, no storm events have occurred since installation so its performance cannot be evaluated. (SWC 1-d2)

Sediment yield from Winter Creek, a 33-square-mile tributary of the Washita River, near Chickasha, Oklahoma, has been dramatically reduced since 9 flood detention reservoirs were installed in the watershed in 1965. The sediment yield in 1966 was 91 percent less than it would have been if reservoirs had not been in place, based upon analysis of data from prior years and adjacent watersheds without reservoirs. This was a year of low rainfall, however, and the finding may not be typical. About 56 percent of the total watershed area drains through flood detention reservoirs. (SWC 1-el)

At Riesel, Texas, sediment yield from a 132-acre conservation-farmed watershed was only 17 percent of that from a 176-acre nonconservation-farmed watershed. Nearly all of the soil loss occurred in four months. In February, the sediment yield from the conservation watershed was 59 percent of that for the nonconservation area; in April, it was 19 percent; in May, 4 percent; and in August, 10 percent. Sediment yields for the non-conservation watershed are less today than in the past. Possibly, changes in farm equipment, the increased use of fertilizer, and the introduction of improved varieties of field crops are responsible for this decrease. (SWC 1-el)

A step-wise multiple regression procedure shows promise as a decided improvement over the common sediment "rating curve" method for estimating sediment load for arid land watersheds, according to findings of the Southwest Watershed Research Center, Tucson, Arizona. The regression procedure shows the sediment concentration to be exponentially related at a significant level to about 6 independent variables, which affect the various particle-size amounts uniquely. Most important of these variables are antecedent moisture conditions in the (ephemeral) stream channel; elapsed time from beginning of the flow; water discharge rate; distance of travel from the center of runoff-producing storm; and probably range cover in the storm area, with respect particularly to the silt and clay fractions. (SWC 1-gl)

3. Roadside sources of sediment and control. An inordinately high proportion of sediment yield in the Southeast comes from unprotected roadbanks. Studies continued to determine the causes of and to develop methods to control sediment yields from highway slopes in Georgia.

A comparison of runoff and soil losses from unprotected and vegetated roadbanks was made on typical Piedmont soils near Cartersville, Georgia. The average sediment yield from two bare roadbanks during 1966 was 127.5 tons/acre. In contrast, the average yield from four nearby banks stabilized with vegetation was 5.3 tons/acre. This is a ratio of about 24 to 1 in favor of the vegetated areas for preventing erosion. Type of plant cover was not a significant factor in preventing erosion; nor did the slope of vegetated banks have a measurable effect on sediment yield. (SWC 1-bl)

In a study of adaptability of species and species-mixture for roadside stabilization in Georgia, results were similar to those of 1965. Three varieties of crownvetch seeded in 1964 and 1965 differed in seeding vigor and cover. Chemung showed best seedling vigor and early cover development; Emeral was second; Penngift, third. Fescue, alone or in mixture with crimson clover, gave quick cover. Nitrogen from the clover stimulated the fescue. English ivy failed at most locations. Vince minor, monkeygrass, daylilies, and honeysuckle survived well on most locations

but were slow to develop cover. Midland bermudagrass and common local bermudagrass survived low winter temperatures for two years in the Blue Ridge Mountains of Georgia at elevations of 1,800 to 4,800 feet. Temperatures were from  $-5^{\circ}$  F. to  $-21^{\circ}$  F. for three consecutive days. (SWC 1-b1)

Studies were started at Athens, Georgia, to determine the water-holding characteristics of disturbed soil materials commonly used in earth structures and on roadside areas. Use of multiple stepwise regressions to analyze available data on soil-water characteristics for southeastern soils gave useful prediction equations. Soil parameters included bulk density, percent clay, silt, sand, and clay plus silt. The textural fractions were found to be the best predictors of available water-holding capacity. Bulk density was a poor predictor. The best prediction equations were:

a. Upper-limit =  $3.51 + 0.64\% \text{ clay} + 0.32\% \text{ silt}$

$$r^2 = 0.801; \text{ d.f.} = 530$$

b. Lower-limit =  $-0.10 + 0.55\% \text{ clay}$

$$r^2 = 0.904; \text{ d.f.} = 530,$$

where the upper-limit and lower-limit are field capacity and wilting point, respectively (percent moisture by volume). Nomographs were constructed for rapid calculations. (SWC 1-b1)

Statewide investigations in Georgia to evaluate mulching methods for stabilizing newly prepared and seeded highway backslopes were continued. Previous tests showed that asphalt spray as part of the treatment decreased the effectiveness of the mulch. Asphalt, however, is considered necessary to prevent blowing of straw mulch by most highway personnel. In 1966, tests were designed to determine the optimum rate of SS-1 asphalt to be incorporated with 2 tons/acre of grain straw. On the basis of these tests an increase in the amount of asphalt mixed with straw tended to increase erosion--at least for rates between 100 and 700 gal./acre. However, due to site and other variables, no real statistical significance was shown in the 1966 tests. (SWC 1-b1)

4. Sediment measuring devices. Two models of the X-ray sediment concentration gauge, developed by Parametrics, Inc., under the auspices of the Sedimentation Committee of the Water Resources Council, were field tested in 1966 at the USDA Sedimentation Laboratory, Oxford, Mississippi. Model A performed encouragingly during a 2-month test period, but was affected by temperature changes and by the age of the instrument. The print-out time of the recorder was also inaccurate. Concentrations of sediment in water at 1,000 p.p.m. were measured over 15-minute periods with a standard deviation of  $\pm 330$  p.p.m. An improved device, Model B, ran for 3 months in the field with no maintenance problems during the

useful life of the Cd-109 radioisotope. The Model B. gauge was more sensitive than its predecessor and had none of the shortcomings of the Model A. (SWC 1-bE1)

At the USDA Sedimentation Laboratory, Oxford, Mississippi, retests of one experimental 3-ft. Coshocton-type runoff sampler and calibration tests of two additional, commercially produced devices resulted in several small modifications in the design. These additional tests have also provided quantitative evidence of the variability in sampler catch between instruments. This type of sampler extracts 1/300 of the runoff volume and has a usable flow capacity of about 4 c.f.s. (SWC 1-bE1)

Results obtained by an automatic pumping sampler, operated on the main stem of the Washita River, Chickasha, Oklahoma, compared favorably with those obtained by the more conventional manually operated samplers. The pumping intake was located 0.7 ft. above the streambed. Duration of the pumping event was about 1 minute and the interval between pumping events varied from 1 to 4 hours, depending upon stage of the river. A trash-free intake for the pumping sampler installed in midstream proved quite satisfactory. Correlations between the two sampling methods were excellent from 100- to 5,000-p.p.m. range of concentrations sampled. (SWC 1-e1)

Development of methods for sampling bedload passing overfall grade control structures was continued on the Calleguas Creek Watershed, near Camarillo, California, with emphasis on ways for handling trash. Work was also begun on developing a larger scale slot-type bedload sampler for the runoff-measuring flumes on the Walnut Gulch Watershed in Arizona. A prototype sampler was fabricated for trial in the 1967 runoff season. (SWC 1-g1)

5. Streambed pollution by pesticides. The 1966 sampling and subsequent chemical analyses of the bed sediments in the Lower Mississippi River and many of its tributaries generally confirm the findings of the 1964 survey. No general buildup of pesticides from on-farm usage was detectable at the 0.1 p.p.m. level. On the other hand, there were heavy contaminations in the streams and tributaries that receive waste effluents from industrial areas where pesticide materials were manufactured or formulated. These findings tend to refute the widely publicized claims that the use of pesticides by Delta farmers has been the cause of recent massive fish kills. The sampling was done by the USDA Sedimentation Laboratory, Oxford, Mississippi, and the chemical analysis was by the USDA Pesticide Monitoring Laboratory, Gulfport, Mississippi. (SWC 1-b4)

## B. Rates and Processes of Reservoir Silting

Studies of data on sedimentation for 968 reservoirs in the United States, made at the USDA Sedimentation Laboratory, Oxford, Mississippi, reveal that the smaller reservoirs are losing capacity at the average rate of 3 percent per year. This means that about 20 percent of the reservoirs studied will be half-filled with sediment in about 30 years, if these rates persist. The overall, average annual depletion rate of 0.2 percent of total reservoir capacity is less alarming. Rates of depletion of reservoir capacity generally decrease as capacity and watershed size increase. The findings tend to strengthen our convictions of the need for persistent efforts in erosion control, in the need for the development of new erosion control methods with the changing times, and in the need for studies of the designs of sediment interceptor structures and sediment bypass systems to preserve investments in reservoir storage capacity. (SWC 1-bE2)

Major equipment alterations to expedite and improve collection of field data in reservoir sedimentation surveys were made by the North Central Watershed Research Center, Columbia, Missouri. Normal operating depth of the fathometer transducer on the survey boat is 2 feet below the water surface, which limits use of the fathometer to water depths greater than 3 feet. Results of the study showed that the transducer could be set 6 inches below the water surface and operated satisfactorily in water depths as shallow as 1.5 feet. This improvement makes possible rapid surveys over more of the reservoir area. A chart recorder was modified to record every 10 feet of distance traveled along a range line as reservoir depth is recorded continuously while the boat moves across the reservoir. This operates satisfactorily at boat speeds up to 2 feet per second. These notable alterations improve the speed and accuracy of reservoir surveys. (SWC 1-c3)

The mechanics of delta formation or sediment deposition in small reservoirs was studied in a 20 ft. x 100 ft. by 3 ft. model basin at the Colorado State University Foothills Campus, Fort Collins, Colorado. Water and sediment were introduced at constant rates into a fixed-bank channel terminating in a reservoir where a constant surface elevation was maintained. The intensity of large-scale motion in the form of secondary currents, surges, and water surface fluctuations was found to be stronger during aggradation of the channel than during degradation and is related to the rate of aggradation. The rate of delta-area growth is a function of sediment inflow and delta thickness. In a study of the size distribution of sediments in a three-dimensional delta, it was found that the internal structure of a delta can be related to overall delta geometry. (SWC 1-18(d3))

C. Mechanics of Sediment Entrainment, Transportation, and Deposition

1. Tagging of silt with radioactive materials. Silt particles, 5 to 50 microns in diameter, were successfully tagged with silver-110 and scandium-46 at the USDA Sedimentation Laboratory, Oxford, Mississippi. The treatment, a modification of that previously used for tagging sand particles, results in only slightly greater radioactivity on the finer fraction of a mixture of sizes. It provides a relatively stable coating of particles for hydrologic or hydraulic research purposes. (SWC 1-bE3)

2. Techniques for the measurement of sand bed movement. The form of sand streambeds varies depending upon the sizes of the sand particles and the hydraulic variables existent. These forms range from a flat, smooth bed to ripples, dunes, and antidunes. The migrations of ripples and dunes are a part of the sediment transport process. Two techniques, using sonar devices, have been devised and used in flumes at the USDA Sedimentation Laboratory, Oxford, Mississippi, to measure the size and frequencies of the bed forms. One uses a single probe to traverse a length of channel and record the irregularities. Autocorrelation studies of bed elevations at pairs of locations, several fixed distances apart, yield a measure of the sizes of the irregularities. The other method employs two stationary sensing units at a measured, fixed distance apart in the direction of flow. Two recordings of the bed forms are obtained as they migrate under the devices. A study of bed elevations at the two sites for differing increments of time permits an evaluation of the speed of migration and the mean length of the dunes. Estimates of bed material transport as bedload may then be made. Amplitudes of the irregularities are recorded in both techniques. Both may presumably be used in natural open-channel flood-flows. (SWC 1-bE3)

D. Stream Channel Morphology and Means and Measures for Channel Stabilization

1. Channel morphology. Observations show that degradation is continuing along the Earsing cutoff on Buffalo Creek near Gardenville, New York, where stream channel processes are being studied. One of the sills built across the channel has been completely exposed on one end by side cutting and local scour. The sills are still satisfactorily stabilizing the channel but immediate remedial action is necessary for their future protection. An analysis of the cutoff and sills is being made to provide an improved basis for design. (SWC 1-a1)

A field study of stability of channels in the Kansas and Nebraska Loess-Drift Hills disclosed that such channels have a predictable behavior. Regression analysis of data obtained from channels in the 9.17-square-mile Sabetha Lake Watershed near Sabetha, Kansas, shows that the erosion or deposition per year per hundred feet of incised channel is correlated ( $R = 0.92$ ) with the hydraulic radius per foot of stage and the watershed drainage area--two easily measured physical characteristics. (SWC 1-18(d3))

Streambed elevations dropped 6 inches to 4 feet, and refilled during the recession of flow, during two bankfull flows in the Alamogordo Creek Experimental Watershed, near Santa Rosa, New Mexico. Net changes in cross-sectional geometry appear to have been general widening of the channels, and slight general degradation. A headcut at the upper end of the branch channel under study receded more than 50 feet during the 1966 summer runoff season. (SWC 1-g2)

2. Stream channel stabilization. A study to determine the utility of jacks and fences for stream channel stabilization and to improve their effectiveness was initiated at the USDA Sedimentation Laboratory, Oxford, Mississippi. Vertical photographs from 3,000 feet were taken of the stream before construction work was started. Locations along a 4-mile reach of Tillatoba Creek, Mississippi, for installation of bank stabilizing structures were selected. A contract has been let for installation of piling and waling fencing and strings of concrete jacks in the selected reach. Arrangements have been made for data collection to start when construction is completed. (SWC 1-b5)

#### E. Valley Sedimentation Rates and Distribution

Valley sedimentation rates have decreased significantly since 1937 in Toby Tubby, Goose and Hurricane valleys in north Mississippi. This, presumably, reflects increasing effectiveness of conservation measures, including continuing construction of detention dams and debris basins in these severely eroded upland valleys. Resurveys of 50 cross sections in these valleys by personnel at the USDA Sedimentation Laboratory, Oxford, Mississippi, indicate average sediment accumulation of about 0.7 foot since 1937. This corresponds to a reduction of about 30 percent in the average annual rate, derived from previous boring data, for 100 years of accelerated soil erosion prior to 1937. (SWC 1-bE2)

#### F. Radiocarbon Dating of Sediments

At the USDA Sedimentation Laboratory, Oxford, Mississippi, the age of the Vicksburg loess was determined by measuring the C-14 content of pulmonate gastropods, "charcoal," and mastodon bones associated with defined stratigraphic units of loess exposed along Highway 61 near Vicksburg, Mississippi. The radiocarbon ages of the exposures range from 25,600 (Farmdale loess) to 17,850 years (Peoria loess) for the several blankets of loess. These ages are in close agreement with those reported for loessial deposits in the upper Mississippi Valley. Blankets of loess older than 25,600 years are evident from borehole investigations of the loessial deposits. (SWC 1-b4)

Carbon-14 measurements of peat and marl samples from the Vermont Wildflower Sanctuary Bog indicate that the bog developed at the rate of 7.2 cm./century, according to determinations made by the USDA Sedimentation Laboratory, Oxford, Mississippi. The basal sedimentary peat and marl [ $11,030 \pm 200$  years and  $11,290 \pm 200$  years B.P. (before present)] of the Vermont Wildflower Sanctuary Bog are about 500 to 800 years younger than the classical Two Creeks forest (11,850 years B.P.) and are broadly correlative with the Champlain sea invasion of the St. Lawrence lowland (11,300 years to 10,500 years B.P.). Valdres ice, which postdates the Two Creeks forest, apparently did not cover northern Vermont. (SWC 1-b4)

The basal peat in the upper Everglades developed during late Hypsithermal time (4,400 years B.P.) when the rising sea level slowed down internal drainage and produced a rise in the Everglades water table. The average rate of peat development in the upper Florida Everglades was about 8.4 cm./century, according to findings of the USDA Sedimentation Laboratory, Oxford, Mississippi. It required about 1200 years for nature to develop the upper 1.8 meters of the original Florida Everglades profile observed in 1914, and only 50 years for drainage to destroy it. (SWC 1-b4)

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AREA 2: HYDROLOGY AND WATER RESOURCES  
RELATED TO AGRICULTURAL WATERSHEDS

Problem: An insight into the operation of the hydrologic cycle in agricultural watersheds is one of the essential segments of knowledge required for successful development, management, and utilization of the Nation's soil and water resources.

There are nearly 12,000 watersheds in the country in the size category commonly encompassed in developments under the Watershed Protection and Flood Prevention Act, the Small Reclamation Projects Act, and similar programs. About 8,300 of these watersheds need project action for development of flood prevention systems, water supply, public recreation areas, and irrigation and drainage enterprises. In addition, it will be necessary to evaluate the hydrologic performance of all these watersheds in connection with programs of comprehensive river basin planning now in progress and projected for the future.

Research-derived procedures for estimating floodflows, water yields, hydrograph shapes, base flow, and ground water accretions in relation to the use and treatment of watershed lands in the various geo-climatic regions of the country are an urgent need. Research on relations between improvement works in upstream tributaries and floodflows and water yields downstream along the principal tributaries and the main stems of major rivers is also a conspicuous need.

This research seeks new knowledge of hydrologic processes in agricultural watersheds. From it are derived prediction equations and criteria for the more efficient design of watershed programs and utilization of water resources.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program involving engineers, geologists, meteorologists, soil scientists, ecologists, and statisticians in both basic and applied research on the hydrology of agricultural watersheds. The primary purpose of this research is to provide hydrologic guidelines for the formulation of an adequate system of interrelated structural developments and associated land treatment measures for the best use or combination of uses of land and water resources within upstream watersheds and river basins of which they are tributary.

The scientific effort directed to this area of research totals 48.84 scientific man-years. Of this number, 8.28 are devoted to studies of precipitation patterns; 10.98 to soil moisture accretion and depletion; 2.79 to ground water accretion, movement and basin recharge; 4.47 to aquifer-streamflow relationships; 12.31 to water yield and water supply and quality; 9.65 to floodflows and storm runoff; and 0.36 to watershed models.

#### PROGRAM OF STATE EXPERIMENT STATIONS

A total of 40 scientific man-years is devoted to this area of research.

#### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

##### A. Precipitation Patterns

1. Precipitation amounts. Precipitation patterns for 12 watersheds varying in size from 116 acres to 43 square miles are being studied at Danville, Vermont, to determine the effect of areal and time variation of precipitation on methods for analyzing hydrograph timing such as time of concentration, time to peak, and lag time. Studies are also being made to evaluate the effects of variation in precipitation characteristics on runoff volume, rate, and conditions antecedent to runoff. A summary report on precipitation characteristics for the Sleepers River Experimental Watershed near Danville, Vermont, is being prepared. (SWC 2-a1)

Studies of precipitation patterns on the 162-square-mile Mahantango Creek Watershed near Klingertown, Pennsylvania, were initiated by the Northeast Watershed Research Center. A network of recording raingages was installed (1) to provide information on the effect of watershed physical characteristics on the production of precipitation; (2) to determine the effectiveness and sensitivity of the precipitation network; and (3) to provide precipitation information in suitable form as input data for other research studies and development of hydrologic models. Gages used in the network record data on punched paper tape suitable for computer processing. The ADP system will make it possible to keep the reduction of precipitation data current and immediately available for hydrologic analysis. (SWC 2-a1)

Sequences of extremely wet and dry periods are essential input to any long-term water yield study. Studies of persistencies of these sequences, using the U.S. Weather Bureau data for several stations in Maryland, have been initiated by the USDA Hydrograph Laboratory, Beltsville, Maryland. Preliminary indications are that the same theoretical distributions will not adequately describe both the wet and dry period sequences. Parts of the analyses for these Maryland stations will be completed in

1967 and submitted for publication. The ultimate goal is to derive generalized relationships for determining the probabilities of obtaining these extremely wet and dry sequences for the entire United States. (SWC 2-aD1)

The distribution of rainfall over a ridge at the North Appalachian Experimental Watershed, Coshocton, Ohio, was studied to define the gage network needed to evaluate the input into a detailed watershed hydrology research program. Twenty wedge-type gages, three recording gages, and three directional gages were established on the ridge having a maximum 100-foot relief in a horizontal distance of 700 feet and ridge line at right angles to the southwest prevailing winds. Catch on a 30-acre pasture area varied with gage location and wind direction. Data in one season showed a significant trend of lesser catch with increasing elevation. Furthermore, one gage caught 9.8 inches in storms with southwest winds--1.1 inches less than the average of all gages. But in storms with southeast winds, the catch from this same gage totaled 4.6 inches--0.4 inch above the average. (SWC 2-cl)

In a study of the precipitation characteristics at the Central Great Plains Experimental Watershed near Hastings, Nebraska, for the period of record 1937 through 1966, large within-basin variations were found for both annual and monthly precipitation. Monthly precipitation over the 1½-mile by 5-mile area varied by as much as 3½ inches. Variations of the same order were found in annual amounts, indicative of the profound effects of convective thunderstorm rainfall in this area. (SWC 2-d2)

Monthly precipitation in the 1130-square-mile Washita River study reach, Chickasha, Oklahoma, has been below the 30-year U.S. Weather Bureau normal during 75 percent of the 60-month period of record obtained by the Southern Great Plains Watershed Research Center. The months with above-normal precipitation have been distributed throughout the period. Differences in annual maximum and annual minimum point rainfall have ranged from 13 to 18 inches over separating distances of 22 to 39 miles. Maximums and minimums have been randomly distributed over the study reach. (SWC 2-el)

Continued investigations into the occurrence of precipitation in mountainous areas of Boise, Idaho, by the Northwest Watershed Research Center, have revealed several precipitation characteristics: (1) Variability in precipitation catch in study areas is directly proportional to the number of gages; (2) precipitation shows a greater increase with elevation during the snowfall-winter season than during the summer season; (3) the probability of occurrence of normal annual precipitation is about 30 percent, or a recurrence interval of between 3 and 4 years; (4) the

coefficient of variation of precipitation obtained by 48 gages spaced 500 feet apart is about 8 percent; and (5) the highest correlations of rainfall catch between surrounding gages occur in a band around the watershed rim rather than in the interior of the basin. (SWC 2-f2)

The performance of shielded and unshielded standard recording precipitation gages indicates that large errors are involved in the measurement of precipitation, according to findings of the Northwest Watershed Research Center, Boise, Idaho. Unshielded gages, over one winter's season, recorded only 80 percent of the snowfall caught by a standard shielded gage. The differences in catch between the two gages and temperature were used to predict windspeed. The prediction equation related windspeed to exponential functions of temperature and the difference in catch. Such predictions make it possible to use a wind adjustment to estimate the "true" precipitation from data obtained from a shielded and unshielded gage. A measure of true precipitation is obtained by use of a vertical orifice that points into the wind and by relating catches at different heights above the ground to the wind variability with height. (SWC 2-f2)

Four gages were added in the past year for more intensive coverage of a 3.2-square-mile subwatershed of Walnut Gulch Watershed, now being used by the Southwest Watershed Research Center, Tucson, Arizona, for verification of both digital and electronic analog watershed models. The difference in estimates of rainfall input, using the original 6-gage and present 10-gage net, to this 3.2-square-mile subwatershed averaged only 0.9 percent for 4 runoff-producing storms in 1966. However, the difference for one storm was as much as 7 percent and estimates were higher in 3 out of 4 of the storms, with the more intensive net. This indicates the difficulty of adequately measuring the rainfall for hydrologic studies even on relatively small semiarid rangeland watersheds, to say nothing of adequately representing its areal distribution in model studies of larger semiarid watersheds. Differences for short intervals within storms, or the positions and values of peak rainfall intensities, are even more difficult to precisely determine and simulate. (SWC 2-g1)

Three major runoff producing storms occurred in the summer of 1966 on the Alamogordo Creek Experimental Watershed, near Santa Rosa, New Mexico. Two averaged more than 2 inches over the watershed. An intense multicellular convective thunderstorm on June 16-17, though not the largest storm of the year, produced a near-record runoff. Rainfall near the center of the watershed exceeded 3.6 inches. The largest rainfall, on August 22-23, was produced by a frontal-convective system, as has occurred also in some previous years. It was associated with a very slow-moving cold front which lasted more than two days and produced widespread storms and flooding in the lower Pecos River Basin. Rainfall on the experimental watershed varied from approximately 1.2 to almost 5.2 inches. The areal distribution was apparently affected by some orographic influence of the escarpment rimming the watershed. (SWC 2-g1)

2. Rainfall intensity-duration. A precipitation network of 52-digital-type recording gages was laid out and installed on the Little River Basin near Tifton, Georgia. Gages are spaced  $1\frac{1}{2}$  miles center to center on a 2-square-mile subwatershed and a 3-square-mile urban watershed, which are scheduled for intensive investigations. Gages in the remaining portion of the network are spaced on 3-mile centers. This network will provide for measurement of precipitation input to the 145-square-mile main experimental watershed and several subwatersheds on Little River Basin for correlation with other components of the hydrologic equation. The network is operated by the Southeast Watershed Research Center from headquarters in Athens, Georgia. (SWC 2-b2)

3. Orographic influences. Data collected by storage precipitation gages from locations in the high mountains of northern Idaho (Palouse River drainage) have been related to elevation in studies at Moscow, Idaho. The correspondence between precipitation catch and elevation in each of three tributaries exhibits a distinct and separate relationship. These relationships remain to be characterized by other definable physical features. (SWC 2-f2)

Additional vectopluiometers were installed late in 1965 near Lompoc, California, for study of land slope influences on precipitation, particularly in winter low-intensity storms. The 1966 data continue to indicate that increased land slope reduces the range of horizontal direction from which rain falls, and that this is especially true for the larger storms. Fourteen storms exceeding 0.25 inch had horizontal vectors generally from the south, on a flatland site; and generally from the west at a hillside site with a north-northwest aspect. The range of vertical vectors of the rainfall was also reduced at the hillside site, and again particularly for the larger storms, exceeding 1.00 inch. The angle of incidence of rainfall at the hillside site was generally nearer horizontal than at the flatland site. At both the flatland and the hillside site, for all storms exceeding 0.25 inch, the maximum departure of the vertical component of the rainfall direction did not exceed  $53^{\circ}$  above the horizontal, and at the hillside site was as low as  $2^{\circ}$  from horizontal in one storm. (SWC 2-gl)

Data from the net of 29 recording and 11 nonrecording gages over an area of approximately 50 square miles, near Tahachapi, California, in 1966, confirmed the general influences of elevation previously reported, with generally higher intensities occurring at the higher elevations, but with the maximum total rainfall occurring on the intermediate slopes, and lowest values of both intensity and total precipitation occurring in the valleys. More notable are deviations from the general elevation relationships, which appear to be recurring at particular gage sites. These deviations probably are in some way related to the land slopes, and possibly to some general pattern of air movement across the study area.

Ninety-four percent of the 1966 rainfall over the Tahachapi storm pattern study area occurred in winter frontal storms. However, very severe summer thunderstorms also occur occasionally at this westernmost edge of the Colorado Basin. (SWC 2-g1)

4. Snow depths. The variability in depths of drifted snow in mountainous terrain is investigated by the Northwest Watershed Research Center, Boise, Idaho. The maximum snow depth in drifts, as observed in study areas, is directly proportional to the land slope and inversely proportional to slope length. Maximum snow depth occurs near midslope in drifts on short moderate slopes (greater than 25 percent) and nearer to the toe of longer gentle slopes (less than 25 percent). Maximum snow density values were associated with maximum depths. Over a 12-foot snow pillow, with an average snow depth of 28 inches, the standard deviation of depths obtained from 1-foot grid points was  $\pm 5$  inches. (SWC 2-f3)

5. Snowmelt. Factors needed to define heat transfer are being measured by the Northwest Watershed Research Center, Boise, Idaho, as part of an expanded research effort on snowmelt and evapotranspiration. Limited albedo measurements obtained over new fallen snow were near 0.71, which lowered to 0.60 within a week because of aging and contamination. Typical albedo values recorded around May 15 over old, dirty snowdrifts on a clear day ranged from 0.57 to 0.60. (SWC 2-f3)

#### B. Soil Moisture Accretion and Depletion

1. Infiltration. Three plots about 100 feet long and 20 feet wide, on a 50-percent slope, and representing concave, straight, and convex shapes, were intensively instrumented for study of surface flow, interflow, and ground water contribution to stream flow in the Sleepers River Experimental Watershed, Danville, Vermont. The primary purpose of the study is to determine how runoff is produced on selected soils and topography. (SWC 2-a2)

Laboratory analyses contracted with the University of Georgia by the USDA Hydrograph Laboratory, Beltsville, Maryland, in the survey of soils on ARS experimental watersheds reported last year, have been completed. Moisture retention in loose aggregate samples were determined at 5 tension points (0.1, 0.3, 0.6, 3.0 and 15 bars). Moisture retentions were also determined for "fist-size" fragments at 0.33-bar tension. The moisture content in the disturbed bulk or "loose-aggregate" samples at 0.33-bar tensions agreed closely with values obtained for the "fist-size" fragments generally conceded to be more representative of soils in-place. Sieved samples are being tested at 15 bars tension in an ARS laboratory to further verify moisture contents in bulk samples tested by the contractor, and to provide information on rock contents in samples. The use of bulk samples in moisture retention tests saves considerable time and labor in soil sampling and in sample preparation. (SWC 2-aD1)

The technique for calculating the storage capacity of soils and predicting infiltration as a function of storage exhaustion, developed by the USDA Hydrograph Laboratory, Beltsville, Maryland, was applied to rainfall on ARS experimental watersheds in water yield computations for periods of several months. Results agreed closely with observed runoff. Numerical experiments applying this technique to design storms indicated that runoff rates and amounts are reduced significantly by agronomic measures on deeper soils but not on shallow soils, and that reductions on deeper soils diminish under wet conditions or as the soil fills up during prolonged rainfall. This systematic technique for computing flood reduction benefits from agronomic measures is important in designing watershed development programs. (SWC 2-aD1)

Field procedures to rapidly determine soil depth have been developed by the Northwest Watershed Research Center, Boise, Idaho. A portable seismic refraction meter has been used to develop isopach maps of soil depth and the fractured layer at the top of basalt, and the top of the solid bedrock. Soil depth determinations were based on a seismic velocity ranging from 600 to 1600 feet per second. (SWC 2-f3)

Soil moisture blocks have been installed at several depths and rain gage locations, representing five range site types, on the Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico. Observations in calendar year 1966 show that, despite an above-normal rainfall year, moisture penetration reached the 24-inch soil depth at only one sample location, and did not reach the 18-inch depth at most of the eleven locations. (SWC 2-g2)

2. Soil moisture balance. A study was made of the composition of forest species to determine if there is any definite relation between forest composition and soil types on the Sleepers River Basin at Danville, Vermont. The climax forest type for this basin is hardwoods. Although coniferous stands are common on abandoned areas, they are usually shaded out by hardwoods within one generation. This study showed that forests with beech composing 30 percent of the basal areas were associated with loams friable to a depth of 3 feet or more, and that forests without beech except in blowdown areas were associated with soils that had a fragipan at an average depth of 18 inches. This information was used to supplement the SCS soils map in more accurately delineating areas of poorly drained soils on maps of small watersheds. (SWC 2-a2)

Studies of no-tillage, continuous corn practices on a watershed at the North Appalachian Experimental Watershed near Coshocton, Ohio, showed that organic residues and manure on the soil surface reduced moisture loss by evaporation. Soil water in the 0- to 7-inch depth of Muskingum silt loam ranged from 25 to 28 percent by volume throughout the growing season in the no-tillage areas, whereas soil water in conventional tillage areas

was twice depleted to wilting point (9 percent). Water-use efficiency in no-tillage corn was 8.7 bushels of corn per acre per inch of water used and 7.7 for conventional corn tillage. (SWC 2-c6)

Studies of soil moisture distribution beneath level terraces in deep loess soil near Council Bluffs, Iowa, showed that drainage occurred in a near-vertical direction with practically no lateral movement. Following the flooding of the terrace channel, drainage was rapid for the first few days, but very slow after 10 days. The estimated average unsaturated hydraulic conductivity of 18 feet of soil profile decreased from a maximum of 2 feet per day to 0.007 during the first 5 days of drainage. Moisture content of the 18-foot soil profile below the terrace channel was higher 80 days after flooding than it was before flooding, even though it was thought to be at field capacity initially. Moisture movement data indicated that as the land surface between the level terraces forms a bench, the flooded area will be more extensive and greater surface storage and intake potentials will develop. Such knowledge of moisture flow patterns, being obtained by the North Central Watershed Research Center, Columbia, Missouri, is critical to the determination of the magnitude of water conservation, recharge to groundwater, and possible hazard of gully wall weakening from increased subsurface water movement to the gully. (SWC 2-c6)

Studies of watershed soil moisture data at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed that watershed moisture sampling programs can be derived to provide values of both soil moisture levels and changes therein to meet certain precision requirements. From the parametric-moisture relationships established by the study, it is possible to select a sampling plan to meet the desired standard error for values of either moisture level or moisture change. For a specific sampling plan, changes in soil moisture can be determined four or five times as precisely as can the level of moisture. Soil moisture on a watershed is a key factor in rainfall-runoff relations, crop production, and water yield. Its evaluation will aid in predicting flood flow and water supply for crops and other uses in this region. (SWC 2-c6)

Soil moisture, rainfall, and runoff measurements are being made on 8 cropland and 8 grassland watersheds, by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma. Rainfall for the year varied from 21.66 inches to 27.39 inches on the various watersheds, well below the normal of 31.60 inches at Chickasha, Oklahoma. Drought periods like the one experienced this year provide opportunities to establish the soil moisture level for incipient runoff, which is important and necessary information for determining the rainfall-runoff relationship. (SWC 2-e2)

3. Vegetative cover. Measurable differences in both runoff rates and amounts were observed for various cover complexes on brown-loam, loessial soils at North Mississippi Branch Experiment Station, Holly Springs, Mississippi. The peak runoff rate from 0.22-acre plots on fallow land was fivefold greater than from plots with bermudagrass cover. The effect of density and height of pasture grass on rainfall retention, or interception, was determined from selected storm hydrographs. Where vegetation (dallisgrass and lespedeza) was 4 inches high, rainfall retention was 0.35 inch. Where the same vegetation was 2 inches high, the retention was only 0.17 inch. Total storm rainfall was 0.73 inch. (SWC 2-b3)

There have been four distinct cropping systems for a 19.2-acre single-cover, unit-source watershed at Watkinsville, Georgia, since 1940. Water yields have varied with each cropping system. During the cotton-oats-cowpeas rowcrop period from 1940-44 average runoff was 16.1 percent of rainfall. Runoff decreased to 10.0 percent during the kudzu period from 1945-49. As the kudzu became well established and rescuegrass was added, runoff dropped to a low of 1.4 percent from 1950-56--the kudzu-rescuegrass period. Then during the Coastal bermudagrass period from 1957-66 runoff increased to 7.3 percent. The increase in runoff during the Coastal bermudagrass period may have been caused by soil compaction due to livestock grazing. The kudzu-rescuegrass cover was not grazed. (SWC 2-b3)

A study of the effect of pasture management practices on volumes of on-site surface runoff was completed at the Central Great Plains Experimental Watershed near Hastings, Nebraska. Data obtained from 1939 through 1945 on 100- x 300-foot plots, showed that runoff from the heavily grazed plots was significantly greater than from the lightly grazed plots (4.2 and 2.0 inches, respectively) and that untreated plots had greater runoff than contour furrowed plots (5.7 and 0.5 inches, respectively). Under conditions of uncontrolled grazing during the period 1947 through 1954, adding two additional contour furrows had little effect on runoff volumes as compared with the original furrow spacing. Pitting of plots with an eccentric one-way reduced total runoff as compared with the untreated plots (8.6 to 12.3 inches). The contour furrowed plots again had significantly less runoff than the untreated plots (2.8 to 12.3 inches). (SWC 2-d1)

Measurements of runoff and the losses of runoff from ponds was continued at three "panspot" range sites near Newell, South Dakota. Panspot sites are localized areas of very low infiltration capacity. They are nearly barren of vegetation and occur quite frequently in soils derived from Pierre shale. Because a large proportion of the runoff occurred as snowmelt on frozen ground, differences in runoff on panspot and sandy range sites were not as great in 1966 as in previous years. (SWC 2-d1)

Studies designed to determine the relationship between the vertical wind profile and vegetation height and density have been initiated by the Northwest Watershed Research Center, Boise, Idaho. Such information will be valuable in determining the effects of vegetation on evapotranspiration and the drifting of snow. Data have been obtained from anemometers placed in a vertical profile over a canopy of sagebrush covering about 16 percent of the surface with average brush height of about 25 cm. The roughness length over the vegetation varied between 1.7 and 2.2 cm. With 5 cm. of snow on the same site, the roughness length was about 0.3 cm. (SWC 2-f4)

The Southwest Watershed Research Center, Tucson, Arizona, has found marked differences in range cover between the Walnut Gulch Experimental Watershed, Tombstone, Arizona, and Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico. Vegetation on two-thirds of the Walnut Gulch drainage area is dominated by desert shrubs, with a very sparse understory of grass--or none at all. The most prevalent grass is black grama (Boutelous eriopoda), with little blue grama. On the other hand, black grama, although present on a few of the sampling units on the Alamogordo Creek Watershed, accounted for little of the grass on any of them, and blue grama (Bouteloua gracilis) appeared on 125 of the total of 129 sampling sites and accounted for half or more of the grass on 84 percent of the sites. These differences in vegetation are not explicable on the basis of annual precipitation, which is essentially equal at the two localities. The altitude of the two watersheds is the same, but the Alamogordo Creek Watershed is 200 miles north of the Walnut Gulch Watershed. Average temperatures are somewhat higher, and the frost-free season is about a month longer at Walnut Gulch than on the Alamogordo Creek Watershed. (SWC 2-g2)

Observations and measurements on a series of hillside plots on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, strongly confirm that crown cover of vegetation (brush), and total ground cover including fragments (over 1 cm. in diameter) on the land surface are major factors in reducing runoff generation. (SWC 2-g2)

4. Watershed evapotranspiration. A comparison has been made at Danville, Vermont, between potential ET estimates computed by the Hamon and Thornthwaite methods and the actual ET determined by subtracting the monthly runoff from the monthly precipitation. If months are used when snow cover is not present and changes in soil moisture are taken into account, the potential ET agrees rather closely with the actual ET. This result is not unexpected since the average annual precipitation of 36 inches is well distributed and the average annual temperature is 43° F. and for July, 69° F. (SWC 2-a2,3)

A procedure was developed in the USDA Hydrograph Laboratory, Beltsville, Maryland, for estimating average hourly evapotranspiration for use in computing flood flows and water yields. The model of Prescott was modified to express evapotranspiration as the product of open pan evaporation, published by the U.S. Weather Bureau, multiplied by a crop growth index. The growth index is the experimentally determined ratio of evapotranspiration to pan evaporation for a given crop and season. Growth indices published for corn, wheat, and pasture varied from 0.4 to 0.8 depending upon season, planting date, growth habit, and harvest dates of crops. Adequate estimates of soil moisture storage recovery were obtained with this model to permit reliable computations of infiltration and runoff volumes on small watersheds over periods as long as 6 months. (SWC 2-aD1)

Watershed evapotranspiration values, derived in a study of water budget based on 26 years of data from complex basins at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed the effect of vegetation on consumptive use of water. A ratio of watershed ET to computed ET values for a lysimeter of uniform deep-rooted crop showed a constant value of 0.68 for the entire 26-year period. For the reforested basin, water use increased more than 25 percent as the trees became established over the water use by the previous cover of povertygrass and shallow-rooted brush. The ratio for the last 15 years remained constant at 0.80. The study also resulted in prediction equations for daily and monthly ET based on climatic, water-availability, and plant-cover factors and related to measured lysimeter ET by multiple regression. Growing season monthly  $R^2$  value was 0.826 and the standard error, 0.64 inch, with mean value of  $ET = 4.44$  inches. Daily  $R^2$  value was 0.863 and standard error, 0.03 inch, with mean value of 0.15 inch. Although there is need for improving the prediction technique, the one developed in this study is practical for evaluating watershed ET under different conditions. (SWC 2-c4)

A procedure for estimating possible evapotranspiration in terms of easily obtainable climatological data has been formulated as part of preliminary investigations of watershed evapotranspiration, by the Northwest Watershed Research Center, Boise, Idaho. Estimates of net radiation and evaporation as related to the vapor deficit in the atmosphere can be made by using linear functions of temperature involving the mean daily temperature and the difference in daily maximum and minimum temperatures when multiplied by a climatologically adjusted day length. These estimates can be employed in a Penman-type, energy budget formulation for computations of possible evapotranspiration. Computed values obtained on monthly basis are as accurate as those obtained by using measured incident solar radiation and humidity. (SWC 2-f4)

### C. Ground Water Accretion, Movement, and Basin Recharge

1. Ground water movement. Studies to identify and measure the geologic components associated with water yields from ponds, pits, and wells for use in predicting ground water availability in relation to agricultural land use practices on the Southern Coastal Plains and Atlantic Coast Flatwoods areas of Georgia, were initiated at Tifton, Georgia, by the Southeast Watershed Research Center. Observations at one pond site show that a clay seal beneath the pond watershed contributes significantly to water yield by preventing deep seepage. The clay seal appears to be continuous throughout the area. This observation indicates that determination of subsurface flow by flow-net techniques and methods of quantitative geomorphology will be feasible. Such subsurface analyses, when combined with surface hydrologic information, will permit a water balance to be determined for the watershed and ground water storage area at the study site. (SWC 2-b4)

Studies in the Ahoskie Creek Experimental Watershed at Ahoskie, North Carolina, show that electrical well logging--E-log--can be useful in ground water investigations. This geophysical method measures electrical potential and resistivity at depths within uncased bore holes. The method gives a measure of porosity and permeability. Formational boundaries and physical characteristics of subsurface formations can be defined. At Ahoskie, definite correlations were observed between E-log determinations, specific yields, and permeabilities of washed, fragmented drill samples. A practical advantage of E-logging is to show where to set well-screens most economically and to best advantage for maximum water yield. Also, E-logs can be used to carry out geologic correlation studies between wells for defining subsurface structure and horizontal changes in lithology. (SWC 2-b4)

Measurement over a period of several years has shown only minor fluctuations in ground water or piezometric levels of Pigeon Roost Creek Experimental Watershed, Holly Springs, Mississippi. In spite of continued subnormal rainfall for the past 5 years, pressure elevations of the semiconfined water table in the Meridian aquifer have remained relatively constant. These data confirm that ground water outflow from the basin, estimated to be 2.3 inches annually, is reasonably constant in both wet and dry years. Baseflow for Pigeon Roost Creek has also remained relatively constant, even though total annual runoff has varied significantly since records began in 1957. (SWC 2-b4)

Studies of aquifer characteristics of basalt have been conducted by the Northwest Watershed Research Center, Boise, Idaho. Subsurface investigations show that basalt is most always aphanitic to micro-crystalline. Because of alteration action by secondary solutions, many minerals of the basalt break down. One of the alteration products, obstructing movement of water, is hydrous iron silicate nontronite. This

clay occurs throughout fractures and structural features of the basalt and reduces the permeability of the aquifer system. Pumping tests have been used to determine the basalt aquifer characteristics and procedures developed to adequately perform such tests. (SWC 2-f1)

2. Basin recharge. In the Edwards Plateau near Sonora, Texas, risers in localized ground water tables have been observed following periods when small rates and volumes of flow in the headwaters area are completely transmitted to groundwater without causing observable inflow to flood detention reservoirs. The solution channels and caverns in the aquifer are capable of passing appreciable rates of flow to reappear as spring flow. (SWC 2-e4)

#### D. Aquifer Streamflow Relations

1. Subsurface contributions to streamflow. Investigations at the North Appalachian Experimental Watershed near Coshocton, Ohio, again confirmed that storm flow volume data from unit source areas (uniform soil, slope, and cover) cannot alone predict flow volumes for larger basins. It was evident that for soils and geologic situations that prevail over large areas of Appalachia, storm flow in streams draining more than a few square miles is comprised of measured flow from the unit subareas plus large flow volumes from shallow underground sources. These studies have shown that runoff production over and through a watershed soil body needs to be related to laboratory studies of the principles of water flow in saturated and unsaturated porous media in order to develop watershed flow system patterns based on measurable physical parameters. This has wide application in the development and use of watershed models for predicting the effect of land use changes on downstream flood flows. (SWC 2-c2)

Watershed studies at Coshocton, Ohio, showed that minimum monthly stream flow from complex basins of 43 to 17,400 acres in size in the North Appalachian area is supplied mostly by discharge from water-bearing rock strata. During the July-November dry season, the minimum flow values ranged from zero to 0.12 inch for a recurrence interval of 20 percent of time. During the January-April wet season, minimum flow values for this frequency ranged from 0.08 to 1.28 inches. Geologic exploration showed that the stream channels of the smallest of these watersheds cut into few, if any, of the water-bearing strata and therefore their minimum flow values were small. Most of the major water-bearing strata were tapped by stream channels of basins draining areas of 1,000 acres. Downstream from this point, channel gradients are low (0.5 percent) and there is little or no increase in minimum flow, i.e., for areas up to 17,400 acres. Such knowledge of the hydrogeology of a basin is one of the important criteria in locating water supply reservoirs. (SWC 2-c5)

2. Channel transmission losses. The reduction in discharge between the Anadarko and Turnpike Stations on the Washita River, observed in 1965 by the Southern Great Plains Watershed Research Center, Chickasha, Oklahoma, appears to have been partially accounted for by increased storage in the areas with overflow along the main stem above Chickasha and on Sugar Creek during the floods of September 1965. Part of this surface flow loss appears to have been recovered as return flow in 1966. This would indicate a benefit by reducing the downstream flood in the fall of 1965 and later sustaining the flow at a higher rate. (SWC 2-e4)

A study was conducted recently in the laboratory at the Southwest Watershed Research Center, in Tucson, Arizona, to determine the possible effects of air entrapped, and of sediments carried in the runoff, on the hydraulic conductivity of the streambed materials. When water was introduced into the top of a sand-gravel column, air trapped in the pores substantially reduced the hydraulic conductivity as compared to its saturated conductivity. Fairly heavy clay concentrations (around 1 percent by weight) also substantially reduced saturated conductivity, mainly in the first half-hour or less of flow. The laboratory values determined corresponded fairly well with rates of infiltration into the channel beds as has been indicated by field measurements in channel reaches of the runoff inflow and outflow. However, they were considerably less than had been indicated by earlier field permeameter tests, using clear water. (SWC 2-g3)

#### E. Water Yield, Water Quality, and Water Supply

1. Low flows. An analysis was made of the 30-day minimum volume of flow for 7 years of record for eight watersheds at Danville, Vermont. The minimum flow volumes have been related to the relative areas occupied by poorly drained and well-drained soils. The analysis indicates that the moisture above field capacity in poorly drained soils with a depth from 12 to 18 inches to the fragipan drains off rapidly, and thus results in lower contributions to the sustained base flow. (SWC 2-a2)

Studies of base flow in streams with drainage areas of 330 acres to 266 square miles in southwestern Wisconsin showed that its variability was related to trends of precipitation rather than land use. The relationship of annual deviations of precipitation and base flow from their respective mean values was independent of the size of the drainage area. The lag time between the beginning of a period of above-normal precipitation and the response in increased base flow varied from a few months up to several years, depending on the severity of the preceding drought and the magnitude of excess precipitation. A trend of decreasing base flow appears within a month or two of the start of the period of subnormal precipitation. The relationships discovered in this study were found to be useful in deriving estimates of base flow for periods in the late 1800's when precipitation data, but no runoff data, were available. (SWC 2-c5)

2. Water yield. For the 106-square-mile upper portion of Hurricane Creek Watershed, in the Southern Coastal Plains, near Hazelhurst, Georgia, approximately 20 percent of the rainfall runs off during the warmer months and about 30 percent runs off during the colder months. The findings by the Southeast Watershed Research Center, Athens, Georgia, are based on analyses of rainfall and runoff data obtained by the SCS and USGS for the 4-year period 1957-1960. Further investigation is needed to verify these relationships since correlation coefficients were rather low, but the findings can offer tentative design guides for this part of the Coastal Plain while additional studies are being made. (SWC 2-b1)

Hillside seeps, common to agricultural land of the North Appalachian area, are a curse to cropping operations and a blessing to water yield. Studies at the North Appalachian Experimental Watershed near Coshocton, Ohio, show that a 2-inch perforated plastic drainage conduit 410 feet long, installed at a hillside seep, yielded 9,000 cu. ft. of water in 7 days,-- or some 3,000 cu. ft. more than the flow from an adjacent 7.5-acre watershed. Peak flow rate reached 9 gallons per minute in one wet period. All the excess soil water in the hillside seep area was not removed by this single drain. Water-flow potentials showed the need for an additional drain. These and additional findings on the seep study area have widespread application in maximizing the use of land and water. (SWC 2-c5)

Water yield maps depicting the normal water yields for Idaho and parts of Utah and Nevada have been prepared at Moscow, Idaho. These maps, drawn to a scale of 1:250,000, were produced by distributing the measured water yield from large watersheds over the watershed area by adjusting for elevation and vegetation. The Soil Conservation Service, Corps of Engineers and others have found immediate use of these maps. Publication is anticipated so that maximum use of the valuable maps may be made by all interested parties. (SWC 2-f4)

3. Water quality. In connection with a study of the quality of water yield from agricultural lands, an automatic pump sampler was developed at the North Appalachian Experimental Watershed, Coshocton, Ohio, and installed and tested on small treated and untreated agricultural watersheds having 25-year hydrologic and cultural records. This development made it possible to obtain samples of runoff water at predetermined time intervals and deliver them to gallon jugs in a field refrigerator. An important feature of the equipment is the "time programmers" which are set at a sampling schedule to provide adequate definition of water quality parameters for a storm-flow period. This sampling system is adaptable to almost any runoff measuring device where electric power is available. (SWC 2-c2)

## F. Floodflows and Storm Runoff

1. Rates of discharge. Existing flow formulas were verified analytically in the USDA Hydrograph Laboratory, Beltsville, Maryland, for steady, uniform flow in smooth-surfaced laboratory flumes, and the apparent and effective channel bottoms were found to be the same. This means that there was a unique flow retardance coefficient for all depths in smooth channels for steady, uniform flow. The flow formulas were also valid for steady flow in rough-surfaced laboratory channels with a static lining if an effective channel bottom was established. The effective channel bottom was found to be at the top of the protruding channel lining. Although there is no need to modify the formulas for steady-flow computations if the effective channel boundary is used, reformulation will be necessary to consider the volume of water below the effective reference in the variable flows encountered in flood routing. Future studies will be twofold: (1) to further test formulations in channel-floodplain transition flows (required data will be forthcoming from a research contract study with Purdue University), and (2) to test the applicability of present steady-flow formulas to the flood routing problem. (SWC 2-aD1)

Investigations by the North Central Watershed Research Center, Columbia, Missouri, showed that land use had a significant effect on storm runoff from loessial watersheds near Treynor, Iowa. Two paired watersheds in contour corn had peak runoff rates of 1.95 and 1.84 inches per hour for an intense uniform storm on June 26, 1966. These values contrast sharply with peak rates of 0.18 and 0.06 inch per hour from grassed and level-terraced watersheds, respectively. Peak rates from the grassed and the level-terraced watersheds were thus 90 and 97 percent less than from the watersheds in corn on the contour. These results are highly significant to engineers and hydrologists who must adequately account for land use effects to produce the most economical designs of culverts, bridges, floodwater-retarding reservoirs, and other water-control structures. (SWC 2-c3)

Data collected on historic cloudbursts for the Pacific Northwest, at Moscow, Idaho, place the estimates of flood peaks at 1,000 to 3,000 c.f.s./sq. mi. For a small experimental watershed near Moscow, Idaho, a local summer storm of 0.3 inch occurring within 5 minutes produced a peak flow of about 450 c.f.s./sq. mi. and caused severe erosion on summer fallow fields. Other, larger watersheds with more cover produced only 1/10th of this peak flow. (SWC 2-f3)

An analysis of rainfall-runoff relationships for a set of 24 dominantly grass-covered plots on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, for 34 storms over a 4-year period, showed that rain-fall intensity and amount were the only factors having a statistically

significant effect on the runoff generation. Basal area, crown spread, and antecedent soil moisture had no statistical effect, despite the fact that three levels of soil moisture were maintained on these plots by means of sprinkler irrigation. (SWC 2-g2)

2. Dynamics of channel flow. In a study of the relation of fluvial landforms to channel hydraulics on the Sleepers River Experimental Watershed, Danville, Vermont, it was found that for drainage areas of less than 1 square mile, living and dead vegetation greatly distorts the relation between discharge and channel form. From the watershed divide to the drainage outlet of these small drainage areas, channel width and depth did not increase downstream with increasing drainage area and discharge. For comparable drainage areas, channels were wider on streams crossing forest than on streams crossing sod. Thus, it appears that the usual relationships between discharge and channel dimensions derived for rivers cannot be applied to small streams without modification. (SWC 2-a1)

The relations between channel dimensions and discharge at five sites having drainage areas varying in size from 0.18 to 42.91 square miles are nearly ideal power functions on the Sleepers River Experimental Watershed, at Danville, Vermont. The relations between channel geometry and discharge in a downstream direction are also power functions but with different constants and exponents. The magnitude of the exponents of these relations indicate the relative sensitivity of parameters to changes in discharge. In the Sleepers River Basin the bankfull discharge is equivalent to 0.06 watershed inches per hour, a discharge equalled or exceeded .015 percent of the time. For a given discharge frequency the mean velocities in the Sleepers River are constant. (SWC 2-a3)

Sequential routing of runoff is used in the USDA Hydrograph Laboratory, Beltsville, Maryland, in contrast to the unit hydrograph theory and the linear reservoir theory. Predominately homogeneous soil zones are grouped and delineated by elevation. Rainfall excess is derived within each zone and converted to rate per foot of slope length to serve as input to the kinematic routing programs for overland flow and subsequent streamflow. Initial testing on Watershed W-4 at Fennimore, Wisconsin, and Watershed W-3 at Hastings, Nebraska, indicates significant success. The major utility of a distributed system is that spatial variation in soils, vegetation, land treatment, geomorphology, and rainfall may be studied as modifiers of watershed hydrologic performance. The one-dimensional system described here is the first step in the study of a multi-dimensional system. A major contribution of this approach is the injection of more rational hydraulic principles into the more usual hydrologic computations. (SWC 2-a1)

## G. Watershed Models

1. Physical characteristics of watersheds. The influence of watershed factors on runoff is being investigated on 10 complex watersheds near Blacksburg, Virginia. Complete, detailed soils maps have been obtained for each watershed together with detailed descriptions for all soil types. All soils that occupy 10 percent or more of each watershed have been sampled by horizons and analyzed for (1) water-holding capacity at 0.1, 0.3, 0.6, 3.0, and 15 atmospheres of pressure; (2) bulk density at the 0.3-atmosphere equilibrium point and at oven-dry conditons; (3) total porosity in percent volume based on a uniform specific gravity of 2.65 for all soils; and (4) saturated conductivity. Topographic maps with contour intervals of 5 feet are about completed for the 10 watersheds. A detailed land-use and cover condition survey is made every year of each watershed. Physiographic factors have been determined for the 10 complex watersheds, such as form factor, compactness coefficient, total watershed relief, average slope, mean elevation, median elevation, drainage density, hypsometric information, and drainage network. A hydrologic model is being developed to use the above information in relating physiographic factors to water yields and flood runoff. (SWC 2-a2,3)

Low-level aerial photography is being used to develop topographic maps of the floodplains and channels of interest of six ARS experimental watersheds. Approximately every 150 feet along the channel, cross-sections are constructed to elevations well above the floodplain. Work completed by the USDA Hydrograph Laboratory, Beltsville, Maryland, on two of the watersheds has been facilitated by the use of electronic digitizing equipment that converts rectangular coordinates of the photogrammetric plotter into a form ready for computer reduction. A 1620 computer is used to convert the rectangular coordinates, at a station, into the appropriate hydraulic geometry figures necessary for flood-routing analysis. In the process of data compilation, use of the electronic digitizing equipment substantially reduces the work time, improves the data reliability, and provides permanent storage of data for future use. Comparison of data derived from photogrammetric methods with data available from previous transit surveys of the main channel on the Hastings, Nebraska, watershed shows very good correlation, in spite of the fact that the transverse channel surveys were not made at exactly the same location. (SWC 2-aD1)

In the Edwards Plateau near Sonora, Texas, a study of the rainfall, runoff, and antecedent conditions by individual storms occurring on seven unit-source watersheds, and a multiple linear correlation and regression analysis of the 1964-65 data indicate: (1) geologic variations may be a larger factor in runoff production than the level of vegetation management; (2) the 15-day antecedent condition is a highly significant runoff

prediction factor; and (3) the 30-minute rainfall intensity is a highly significant runoff prediction factor. The latter two factors give a correlation coefficient of 0.851, which is statistically significant at the 99-percent level. (SWC 2-e2)

2. Digital models. Computer programs developed in the USDA Hydrograph Laboratory, Beltsville, Maryland, for computations of infiltration, rainfall excess, hydrographs of inflow to streams, and flood routing were placed in a sequence for computations of surface flows on agricultural watersheds. In August 1966, the Hydrograph Laboratory hosted a 3-day interagency seminar at Beltsville, Maryland, to review five digital models selected for diversity of hydrologic concepts, including the working models of the Soil Conservation Service and the U.S. Weather Bureau and the research models of the Tennessee Valley Authority, Stanford University, and the USDA Hydrograph Laboratory. Several of these models have since been adapted for trial applications to indicate the adequacy of on-going programs of data collection and research at several ARS watershed research centers. (SWC 2-aD1)

At Riesel, Texas, runoff from a native grass watershed was computed using a rainfall-runoff-soil moisture relation developed for the Blacklands of Texas and compared with the measured runoff. For an 11-year period, 1956-1966, the computed runoff was 54.56 inches and the measured runoff was 54.49 inches, a difference of only .07 inch. The good agreement indicates that the procedure is satisfactory for long-term water yield estimates. However, for individual storms, larger differences were observed. (SWC 2-e2)

#### H. Hydrologic Data Releases

The compilation and publication of selected hydrologic data for all Agricultural Research Service experimental watersheds is a continuing program. The 1962 hydrologic data have been prepared for publication. It is anticipated that hydrologic data for subsequent years will be published at 6-month intervals until they are current and then on an annual basis. The hydrologic data consist of: Monthly precipitation and runoff; annual maximum discharges and annual maximum runoff volumes for various durations from 1 hour to 8 days; daily precipitation, air temperature, and discharge for the larger experimental watersheds; tabular data and graphs for selected runoff events; description of various watershed characteristics; and topographical, geological and isohyetal maps. (SWC 2)

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### AREA 3: HYDRAULICS OF IRRIGATION, DRAINAGE, AND WATERSHED STRUCTURES, CHANNELS AND FACILITIES

Problem: Water control structures of various types represent the largest part of the public and private cost for watershed protection and development programs. They are also essential, and expensive, features for irrigation and drainage developments. Research on the hydraulic design of water control structures will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly failure. All items of costs not required for safe functioning of structures must be eliminated.

Development of new concepts in the geometry of spillways, drop structures, and stilling basins at pipe outlets and below overfall structures are included in this research. Other studies include development of new and improved devices for control of floating debris and vortices at the entrance to closed conduit spillways; investigations of energy losses associated with various components of water control structures, hydraulic jumps, the dynamics of overland flow and flood wave velocities and energy gradients in channels of various roughnesses; and development of improved flumes, weirs, gates, and rating sections for streamflow and water discharge measurement. The hydraulic properties of various grasses and other vegetation in water channels are also determined and the effectiveness of mats and mulching materials as an aid in the establishment of grass-lined channels and waterways are tested and evaluated.

It is not possible nor desirable to model the many hundreds of agriculture-related water control structures built each year, as is the usual custom with the larger dams and spillways on the main river systems. This research, instead, seeks to establish principles and develop dimensionless designs which can be adapted to various site situations and size requirements on individual farms and ranches and in upstream watersheds.

#### USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program in which hydraulic and agricultural engineers are engaged in both basic and applied research on the hydraulic performance and engineering design of water control structures and channels. The studies are oriented primarily to provide information relating to the types of structures and channels involved in group irrigation, drainage and watershed protection activities. The scientific effort devoted to this area of research totals 5.48 man-years in the reporting period. Of this number, 1.39 man-years were devoted to basic studies of hydraulic phenomena; 3.26 to criteria for hydraulic design of water control structures; and .83 to flow measurement and water-metering devices.

## PROGRAM OF STATE EXPERIMENT STATIONS

A total of 5 scientific man-years is devoted to this area of research.

### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

#### A. Basic Studies of Hydraulic Phenomena

The experimental setup at Stillwater, Oklahoma, for investigation of spatially varied flow in agricultural conservation channels was revised to expand the types of tests that could be conducted. A model study was made of the complex of five structures needed to divide, control, and measure two flow components--one into the upper end of the channel and the other over the side. The new arrangement makes it possible to simulate any section of a given length diversion or terrace channel and also provides for refinement of measurements of spatially varied unsteady flow. A major part of the construction work required for improvement of the facilities was completed. (SWC 3-el)

#### B. Criteria for Hydraulic Design of Water Control Structures

Studies in the hydraulic laboratory at Minneapolis, Minnesota, showed that an abrupt change in the flow cross section from a circular pipe to a rectangular open channel is best effected when the rectangular channel width is equal to the pipe diameter. Wider rectangular open channels permit spreading of the jet when it hits the open channel floor and result in high waves at the side walls and diagonal waves throughout the length of the downstream channel. These disturbances are suppressed when the rectangular channel width is equal to the pipe diameter. The studies also showed no adverse effect on the flow when the transition floor is lowered below the pipe and a widened section up to 0.5 pipe diameter long is used between the pipe and the rectangular open channel to permit linear expansion of the pipe. These findings make it possible to design simpler, yet fully adequate, transitions between circular pipes and rectangular channels than has heretofore been possible. (SWC 3-cl)

It was found at Minneapolis, Minnesota, that the entrance energy loss coefficients in any two-way drop inlet having a well-shaped elbow and transition between the drop inlet and the barrel are low and identical for each of the five elbow and transition forms and combination of forms tested. This finding shows that the form of the elbow and transition need not be based on considerations involving the conservation of energy and provides maximum flexibility to the designer in selecting the form most appropriate for the site conditions. (SWC 3-cl)

At Stillwater, Oklahoma, skirts on full-size trash racks were found to be most effective at intercepting floating trash approaching a two-way

drop inlet. The drop inlet was a 1D x 3D structure for a 24-inch concrete pipeline. (D is the pipe diameter.) The skirts, which can be of solid concrete or of steel mesh, should extend a vertical distance of D/2 above to about D/3 below the drop inlet crest. (SWC 3-e2)

At Stillwater, Oklahoma, model studies proved to be economically justifiable when applied to the design of relatively small channel improvement works needed for an urban floodwater disposal system. Reshaping forebay and exit boundaries for a large 3-tube culvert to conform to observed streamlines reduced back eddies. The reshaped areas needed were found to be smaller than had been planned, which reduced land acquisition, excavation, and riprap costs. The hydraulic design for the difficult channel junction was verified using a 1:40 scale model. (SWC 3-e2)

### C. Flow Measurement and Water-Metering Devices

At Stillwater, Oklahoma, a calibration by hydraulic model was made of Flume No. 1 on the Walnut Gulch Experimental Watershed, Tombstone, Arizona. The design capacity of the flume is 22,500 c.f.s., making it the largest known precalibrated flow measuring device. Model studies produced a satisfactory calibration for heads above 1.5 feet. Controls were required in the stream channel thalweg to remove variability in approach flow patterns which affected the calibration. The highest flow passed by the flume was 26,000 c.f.s. but, at this rate, wave action caused overtopping of the right wingwall 75 percent of the time. (SWC 3-e1)

A model rating was also made at Stillwater, Oklahoma, of the head-discharge relation for Flume No. 11 on the Walnut Gulch Experimental Watershed, Tombstone, Arizona. The capacity was found to be 5,930 c.f.s. at a head of 10.0 feet; at greater heads, overtopping occurred on the right side. Some irregularity of the discharge coefficient, attributed to high approach velocity, was observed in the 2.5- to 3.5-foot head range. It was also shown that bends in the approach channel caused a gravel mound to form on the bed of the stream, resulting in variability in the low flow approach and demonstrating the need for control works in the channel thalweg to achieve uniformity of approach and stability of the head-discharge relationship at low stages. (SWC 3-e1)

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#### AREA 4: CONSERVATION OF WATER SUPPLIES FOR AGRICULTURAL USE

Problem: The increased competition agriculture is facing from industry and domestic users for a limited water supply requires the development of new sources of farm water supply as well as increased efficiency in the collection, storage, conveyance and use of existing supplies.

An estimated 12 million acre-feet of water is lost annually by evaporation from large reservoirs and 20 million acre-feet during conveyance in irrigation water canals.

Falling water tables resulting from withdrawals exceeding recharge are increasing pumping costs and the danger of depleting the supply over an appreciable area. Economical procedures for clarification of water of impaired quality would speed recharge.

The conversion of cropland to grazing land requires an adequate livestock water supply strategically located to facilitate uniform grazing and thus preserve the newly developed pastures. This is also a critical problem on many established dryland grazing areas.

The rapidly increasing use of farm chemicals poses a potential threat to the quality of water moving off of or through the soil of farm fields. Knowledge of the mechanics involved and the magnitude of the threat is needed so the development of management methods to prevent contamination of urgently needed water supplies can move forward without delay.

Phreatophytes are charged with using 20 to 25 million acre-feet of water in the 17 Western States. Eradication of nonbeneficial plants and replacement with vegetation of economic value would greatly benefit rangeland areas.

#### USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water conservation, employing agricultural and hydraulic engineers, soil physicists and chemists, and geologists. The work is in progress at the U.S. Water Conservation Laboratory, Phoenix, Arizona, and at physiographic area research centers and field stations throughout the United States. In addition, three PL-480 projects on water conservation are in progress in Israel. The scientific and engineering effort in this area totals 26.6 professional man-years per year. Of this total, 6.7 are devoted to control of seepage from water storage and conveyance structures and suppression of evaporation from surfaces; 5.5 to farm water supplies, structures, and water measurement; 10.5 to methods, practices and devices for ground water recharge; and 3.9 to contaminated and wasted waters.

## PROGRAM OF STATE EXPERIMENT STATIONS

A total of 6 scientific man-years is devoted to this area of research.

### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

#### A. Control of Seepage from Water Storage and Conveyance Structures and Suppression of Evaporation from Surfaces

1. Seepage. The loss of water from water collection, conveyance or storage structures is a real loss to the immediate farmer even though seepage water that moves to underground aquifers may be later recovered by pumping. When seepage causes high water tables, drainage and salinity problems frequently result.

A suitable laboratory procedure has been developed at Reno, Nevada, to test the seepage rates of playa sediments. Under a 5-foot head, seepage losses through a 2-inch layer of these sediments have varied from .004 ft./day to .035 ft./day. Most of the sediments seep less water than would be lost from evaporation. After drying, some sediments become more dense and less permeable, a characteristic highly desirable for a low-cost surface seal. At this point in the study, it appears that a seal of playa sediment combined with an effective, low-cost soil sterilant would be a seal ideal for many purposes.

Water-borne bentonite seals were tested for suitability for reservoirs and channels in field studies in Nevada. The seals were short lived, lasting between one and five dryings. Surface blankets are more effective, but continue to deteriorate with time. Four years after installation they were 40 percent effective. The buried seals (blanket and membrane) have been the best seals developed to date, but they continue to decline slowly with time. Four years after installation, these seals seep 0.15 ft. of water per day, but are still 85 percent effective as compared with untreated reservoirs.

Trampling buried bentonite seals with a saddle horse (at a different location than above) increased seepage rates by 33 percent (from 0.30 to 0.40 ft./day). Trampling of the untreated reservoir increased the seepage rate nearly 40 percent (from 1.65 to 2.29 ft./day). Treated reservoirs covered with gravel were not affected by trampling. (SWC 4-g3)

After 13 years, buried vinyl and polyethylene film linings continue to control seepage completely in the test reservoirs at Logan, Utah. Butyl continues to be the only membrane lining material tested that has demonstrated it will withstand outdoor exposure over an extended period. One or two others hold promise in this respect. (SWC 4-g3)

The use of sodium carbonate as a soil-dispersing agent to reduce seepage was evaluated in two stock ponds by the U.S. Water Conservation Laboratory, Phoenix, Arizona. One pond is still maintaining a low seepage rate, 0.4 cm. per day, 13 months after treatment. This treatment has already lasted as long as the tetrasodium pyrophosphate treatment used previously, and chemical soil analyses indicate that it will persist longer. The second pond's seepage rate increased from 0.4 to 0.8 cm. per day from September 1965 to May 1966. In November 1966, 91 kilograms of sodium carbonate and 136 kilograms of sodium chloride were broadcast on the 1,022 cubic meters of pond water to precipitate the calcium and magnesium in the water and to add sodium to the soil. One month after treatment, the seepage had decreased to 0.4 cm. per day. The periodic addition of salt to the pond water appears to be a simple, inexpensive method of maintaining a low seepage loss. (SWC 4-gG1)

A satisfactory technique was developed at the U.S. Water Conservation Laboratory for evaluating seepage from open channels or reservoirs by measuring the rate of penetration of a salt wave in the bottom material. The salt wave is created by maintaining a layer of calcium chloride or aluminum sulfate crystals on the bottom for approximately five minutes. After some measured time, the depth of the peak salt concentration in the bottom material is determined with a specially designed electrical conductivity probe. The seepage rate is obtained by multiplying the rate of advance of the salt peak by the porosity of the bottom material. Laboratory and field studies have shown that the technique is accurate as well as convenient. Its field application is not as dependent on favorable water and bottom conditions as is the seepage meter technique.

Experiences with the double-tube method indicated that the diameter of the outer tube should be larger than the theoretical minimum because of soil disturbance. Field studies with different tube diameters showed that tube-size combinations of 5 inches and 10 inches, and of 4 inches and 8 inches, are more satisfactory than the 5- and 3-inch combination used in earlier work.

The average hydraulic conductivity of a porous medium having different hydraulic conductivities randomly distributed was found at the U.S. Water Conservation Laboratory to be better estimated by the geometric mean than by the arithmetic mean. This was shown by electric analog studies for a number of media with different random hydraulic-conductivity distributions.

A satisfactory rapid-response multiple-tensiometer system was developed and field-tested at the U.S. Water Conservation Laboratory. The system utilizes a motor-driven scanning valve which connects each tensiometer in turn to a pressure transducer whose signal is registered on a millivolt recorder. Field use of such a system requires adequate heat insulation of tensiometer leads exposed to the atmosphere to avoid erratic pressure records due to short-term temperature changes. (SWC 4-gG1)

2. Evaporation from soil and plant surfaces. A comparison was made at the U.S. Water Conservation Laboratory of evaporation from an irrigated sorghum crop as measured by lysimeters and by depletion of water from a 170-cm. soil profile. Sufficient water was applied during irrigation to insure drainage through the 170-cm. depth. As anticipated, internal drainage caused the depletion rate to significantly exceed evaporation as measured by lysimeters for several days after irrigation. An important finding was the fact that 200 hours after an irrigation on June 1, water began to move upward into the root zone from below the 170-cm. depth. Thirty days after the June 1 irrigation, when the root zone soil had dried out sufficiently to severely stress the sorghum plants, this upward water movement amounted to 3 to 4 mm. per day, or about 30 percent of the total consumptive use rate of the crop. (SWC 4-gG2)

A computer model was developed at Lompoc, California, to simulate drainage and evapotranspiration processes at naturally vegetated sites. This approach divided the soil into imaginary depth layers and performed day-by-day calculations for the layers. The rates of drainage were functions of moisture contents and properties of the soil layers. The rates of evapotranspiration were related to the evaporation potential and were functions of the amounts of available moisture and the depth positions of the various soil layers. Viewed overall, the model appears to offer considerable promise as a predictive tool although initial tests of the model resulted in unacceptable errors from several sources. (SWC 4-g2)

Equipment and procedures were perfected at the U.S. Water Conservation Laboratory for the remote sensing of soil surface temperatures with an estimated accuracy of 0.2 degrees C. Through remote measurement of the surface temperature of bare, wet soil in a normal field exposure, the surface vapor pressures could be accurately determined. From such data, it was found that the logarithmic wind law is a simple and very adequate description of the vapor transfer immediately above the evaporative soil surface. Continuous monitoring of far infrared sky radiation revealed significant changes during the day in the Phoenix area. Changes appear to be correlated with the ozone concentration near the surface. (SWC 4-gG4)

The applicability of Darcy's law to saturated water flow through a 50- to 500-micron sand, Boise sandstone, and a ceramic plate of 0.1-micron nominal pore diameter was tested at the U.S. Water Conservation Laboratory. No deviations from Darcy's law were found for the three materials. However, osmotic effects, caused by differences in solubility of the two sides of the plate, were observed in flow through the ceramic. Flow measurements and solution concentration measurements demonstrated that osmotic forces appreciably affect the flow of water through ceramics of 0.1-micron pore diameter. When osmotic effects were accounted for, the flow velocity was proportional to the pressure gradient and in accord with Darcy's law. (SWC 4-gG4)

3. Evaporation from water surfaces. A stable, long-chain alkanol dispersion developed at the U.S. Water Conservation Laboratory can be made in pourable concentrations up to 10 percent and then diluted with tap water to highly stable 1-percent dispersions for application with simple, automatic equipment to control evaporation from water surfaces. These dispersions reduced evaporation by 25 percent for 30 days, when applied at the rate of 0.7 gram of alkanol per square meter per month. The film generation rate of the dispersions is significantly faster than that of powdered alkanol. These dispersions are not discrete alkanol particles as reported by others. Instead, microscopic examination indicates a sol-type structure which is extremely stable, yet permits rapid release of the alkanol when applied to the water surface.

Other studies at the U.S. Water Conservation Laboratory on the long-term effect of perlite ore floating on surface of water in 2.7-meter-diameter tanks showed evaporation was initially reduced 30 to 35 percent. After five months, the evaporation reduction was 10 percent. During this time, 60 percent of the perlite was blown off or sank. On a 12 x 30-meter lined pond, a 2-month test showed the perlite would reduce evaporation 30 to 40 percent. This included periods when 20 to 50 percent of the pond was uncovered because of wind moving the cover. (SWC 4-gG2)

#### B. Farm Water Supplies, Structures and Water Measurement

1. Water harvest. In a study of infiltration control at the U.S. Water Conservation Laboratory, soil flocculation-deflocculation behavior as influenced by sodium and calcium ions and electrolyte concentration varied markedly for different soils. The differences could not be explained on the basis of the commonly used criteria for characterizing soil materials, and more critical evaluation of the physical-chemical properties was required. By computing the swelling of soils as a function of electrolyte composition, using the diffuse double-layer theory, satisfactory agreement between the theoretical and experimental flow rates of solutions through artificially prepared soil columns was obtained. (SWC 4-gG3)

At the U.S. Water Conservation Laboratory, analyses of water collected from asphalt pavements for water harvest sprayed with four different surface coatings have shown that discoloration of water can be significantly reduced by application of a low-cost protective coating to the asphalt surface. Field studies have shown that flaked aluminum in a latex emulsion can reduce the discoloration by more than 90 percent. These coatings serve a twofold purpose: better quality water is obtained and the life of the asphalt pavement is increased. (SWC 4-gG3)

Tests in Utah confirmed the inadequacies of low-density black polyethylene as catchment liners for water harvesting. A polyethylene-vinyl-acetate copolymer also proved to have about the same limitations. (SWC 4-g3)

At Akron, Colorado, plots 50 x 100 feet, lined with sheetmetal, yielded 24,560 gallons of water in 1966. The yield represented 57 percent of the total possible catch. Approximately 9,500 gallons of water were collected from grass plots on 1-percent slopes, for a 22-percent water yield. Runoff yields for individual storms varied with rainfall intensities. Yields as high as 90 percent were obtained from the most intense storms. (SWC 4-3(d1) Rev.)

In a PL-480-supported study at the Volcani Institute of Agricultural Research, Rehovot, Israel, on methods for sealing and stabilizing soil surfaces to increase runoff, it was found that surface coats (of petroleum products) or crusts generally increase runoff most markedly from sandy soils rather than from fine-grained soils. Cracks develop easier in fine-grained soils, and may offset the effect of the coating material. Sodict treatments, although very effective in sealing the soil surface, cause marked swelling and shrinkage and, therefore, may increase soil cracking. In field tests, greatest erosion occurred in the salt-treated plots. (A10-SWC-36)

2. Surface reservoirs. The availability of water for irrigation, especially during periods of drought, is the key to increased food and fiber production in subhumid and humid regions. Because of lack of suitable subsurface water in many areas, supplies of supplemental water must come from surface reservoirs. A 15-year study on a claypan soil area of central Missouri, has shown that good techniques in reservoir construction can reduce seepage losses from 2 or 2-1/2 feet per year to 1 foot per year. Average annual evaporation plus seepage losses from a 16-acre reservoir at McCredie, Missouri, were 46 inches (1951-1966). Twelve inches were lost as a result of seepage and 34 inches as a result of evaporation. This reservoir was carefully constructed to prevent high seepage losses. The retention dam was adequately cored to minimize seepage through the dam and a compacted clay blanket was laid over alluvial soils of the impoundment area. Observations on a 1-acre pond about one-half mile from the reservoir showed seepage losses of more than twice those from the 16-acre reservoir. This pond was also constructed with a cored retention dam, but nothing was done to the impoundment area. In light of the increasing number of reservoirs being built and the increased value of impounded water for irrigation purposes, water saved by seepage and evaporation reduction from reservoirs is particularly important. (SWC 4-cl)

Rainfall totaled 250 acre-feet in 1966 on the 57-acre watershed above an instrumented pond 2.5 acres in surface area near Tifton, Georgia. Of this amount, 49 acre-feet, or 19 percent, reached the pond as surface plus subsurface flow. An additional 9 acre-feet was from rain directly on the pond, totaling 259 acre-feet of available water. Losses from the pond totaled 46 acre-feet through the spillway and 11 acre-feet by evaporation, with but 0.6 acre-foot being used for irrigation. The total available for irrigation during the 5-month period of May-September included 9 acre-feet lost through the spillway and 10 acre-feet stored in the pond, in addition to the 0.6 acre-foot used. These values suggest that 15 to 20 acres of crops

could be irrigated easily from this pond, if the design were altered to store all runoff in the summer months. A tight clay layer lies 5 to 15 feet below the land surface in this watershed. The material above the clay is permeable sand, silt, sandy loam and sandy clay soil that provides a good ground-water collection area for the pond. Studies are continuing to develop a quantitative evaluation of the ground water beneath the watershed and to measure the surface plus subsurface inflow to the pond. (SWC 4-b1)

3. Water measurement and control structures. Studies at the U.S. Water Conservation Laboratory show the elbow flow meter can be converted into a quantity recording meter by replacing the differential pressure manometer, which is normally attached to pressure taps on the inside and outside of the elbow bend, with a low-cost, household water meter. This shunt flow system can be easily calibrated to determine the linear relation between shunt flow and mainline flow.

Theoretical analyses indicate that target meters can be designed to indicate direct discharge in any channel, regardless of configuration. Irregular channel cross sections require graphical techniques to determine the blade shape. With this type of meter, the target blade is shaped in such a way that the total force of a submerged element is proportional to the discharge and is independent of flow depth.

Theoretical equations that adequately describe the discharge-depth relation for critical depth flumes, but are difficult to use because of their implicit nature, have been conditioned for routine solution with computers. This permits the design of flume configurations to accommodate specific requirements of submergence flow range and sensitivity. (SWC 4-gG5)

The fluorescent dye dilution method of water measurement is potentially capable of accurate measurement of irrigation water. Flow measurement in open channels using the fluorometric method was tested in low-velocity, unlined irrigation canals and in a shallow, turbulent stream channel at Twin Falls, Idaho. Commercially available Rhodamine WT dye was used as the tracer material. Tests were repeated so that several measurements at the same discharge could be compared. The repeated measurements generally were within  $\pm 10$  percent of the mean. Measurements in the shallow, turbulent stream were within  $\pm 5$  percent of the mean. These results indicated that other variables such as large-scale meandering of the main flow stream in the channel can affect the dye concentration at a channel section and cause differences in measurements of as much as 25 percent with nearly identical test conditions. The accuracy of measurement in low-velocity channels using this method was not acceptable for the desired uses. (SWC 5-f2)

Trapezoidal measuring flumes are well adapted to commonly used trapezoidal concrete farm ditches for conveyance of irrigation water. At Twin Falls, Idaho, portable forms were designed and constructed for forming trapezoidal flumes in existing farm concrete ditches. Field tests conducted on several installations during the 1966 irrigation season indicated that the flumes

were entirely satisfactory. Several irrigation companies are now installing these flumes using plans and techniques developed at the Snake River Conservation Research Center. Fiberglass flumes of the same basic dimensions are also being produced commercially. Small V-notch flumes for furrow flows (0.2 to 32 g.p.m.) constructed from fiberglass were also developed. (SWC 5-f2)

Modern fabrication methods and new materials have resulted in a variety of new types of drop-check structures for small-unlined irrigation ditches. A field study was initiated near Twin Falls, Idaho, to evaluate the performance of drop-check structures. Thirty-one structures, representing seventeen designs, were installed in a field ditch. These included prefabricated commercially available units and others constructed using standard Soil Conservation Service plans. The performance of these structures was evaluated by observing variables such as flow velocities, stilling basin operation, energy dissipation, erosion and bank cutting, structural adequacy and cost. The standard SCS structures generally operated successfully but were the most expensive to install. The prefabricated, commercially available structures did not operate successfully, in most cases, because of inadequate stilling basins. (SWC 5-f2)

Outlet structures to control and properly distribute the discharge of irrigation water through gated tile outlets were investigated at the U.S. Water Conservation Laboratory through a field study of existing devices, construction of some preliminary field models, and a laboratory investigation using a  $\frac{1}{4}$ -scale model in a sand tank. The most promising basic design for the structure consists of discharging the flow vertically through the top of a box attached to the tile outlet or by breaking and opening the top of the tile near the existing outlet and capping the end. The vertical discharge helps dissipate the erosive energy and with suitable baffling or apron design, permits uniform distribution of the flow onto the soil at less than the erosive velocity. (SWC 4-gG5)

### C. Methods, Practices and Devices for Ground Water Recharge

1. Recharge methods and facilities. At Bushland, Texas, various methods of injecting runoff water into the water-bearing formation are being investigated. The surface soils are relatively impermeable; therefore, recharge through water wells has been considered the most practical method in the past. There are about 60 feet of dry sand above the water table (beginning about 90 feet below the ground surface). Shafts drilled into the dry sand have been tested as an alternative recharge method. Recharge through shafts should reduce the amount of air carried into the saturated portion of the aquifer, should reduce bacterial contamination of the aquifer, and should provide excellent sand filtration before the water reaches a point of possible withdrawal. Tests of plain shafts were disappointing. The recharge rate was only 200 g.p.m. per shaft. However, by mining a cavity at a depth of 90 feet, recharge rate was increased. The cavity was about 3 feet high, and 18 to 20 feet in diameter, having a triangular cross section. The recharge rate was increased threefold to over 600 g.p.m. by the cavity. The

shaft had a constant recharge specific capacity, which suggests that recharge rate was directly proportional to the surface area of the cavity. Therefore, increasing the size of the cavity still more should increase capacity in direct proportion. It is concluded that this recharge method has considerable potential. (SWC 4-13(e2))

At Bushland, Texas, pumping tests, started 8 months after recharge of 61 acre-feet of runoff water from playa lakes, revealed the production rate of one irrigation well was reduced. Almost twice as much total gas existed in water pumped from the well after recharge as exists in native ground water. The recharge water was much cooler than ground water; therefore, it contained more air in solution than native ground water. Upon warming slightly in the aquifer, some of the air was released from solution to form bubbles in the aquifer, thus reducing the permeability of the formation. After pumping 37.5 acre-feet of water, the production rate of the well returned to normal, although the total gas content of pumped water was still higher than for native ground water.

While pumping these 37.5 acre-feet of water, about 9,000 pounds of formation sand also were pumped from the well. The well produced very little sand before recharge. Chemical determinations on the recharge water, pumped water, and ground water indicate that the recharge water dissolved calcium and magnesium from the formation near the well. The formation contains many small and large nodules made of fine sand cemented together with calcium and magnesium compounds. Solution of calcium and magnesium cementing compounds effectively reduced the size of the formation particles, thus causing increased movement of sand into the well. (SWC 4-13(e2))

In the San Joaquin Valley of California, the infiltration rate of a sandy clay loam layer at the 24- to 33-inch depth of a sandy loam profile was about 50 times greater than that of the surface sandy loam layer. The infiltrometers had been installed so that the infiltration rates of (a) the surface horizon, (b) the surface sandy loam layer plus the sandy clay loam layer, and (c) the sandy clay loam layer alone would be measured. Studies as to cause of this higher infiltration rate are continuing, attention now being directed toward stabilization of the soil structure of the sandy clay loam layer by free iron oxides. (SWC 4-g2)

A prototype permeability cell equipped with strain gages has been developed to study salt-associated permeability changes of confined, highly compacted clay layers. These cells will be used to investigate soil and water quality parameters that would play a predominate role in the storage of highly saline drainage waters, as is being contemplated for the proposed San Joaquin Valley Master Drain system. (SWC 4-g2)

2. Water clarification. Soil clogging is essentially a surface sealing process according to findings at Fresno, California. For turbidities composed of a range of grain sizes, clogging is initiated by the deposition of a surface layer which is graded due to the gravitational acceleration of coarser particles. The primary clogging process is the straining of finer particles from the flowing water by the graded, "depositional layer." An equation was developed which predicts the accumulated flow-time relationships for a range of concentrations of a specific turbidity. Even coarse-grained porous media clogged at turbid water concentrations as low as 50 p.p.m. The use of desilting or stilling basins may actually increase rather than alleviate the clogging problem. (SWC 4-g2)

Laboratory and mathematical studies were initiated at the U.S. Water Conservation Laboratory to develop a theoretical foundation for scheduling intermittent inundation of ground water recharge basins with low-quality water. A vertical column system incorporating gamma radiation scanning and closely spaced strain gage transducer-tensiometers was used to obtain experimental data. Several soil profiles, drainage cycles, and inundation cycles were investigated. The developed theory satisfactorily explained the infiltration and drainage phenomena simulated in the soil column. Computer programs were written for numerically solving the flow equations and predicting the experimental results. When computations are complete, the numerical and experimental results will be compared and conclusions reached on the accuracy of the numerical predictive approach. (SWC 4-gG3)

In a PL-480-supported study at Technion-Israel Institute of Technology, Haifa, Israel, experiments were performed on the flocculation of secondary effluents of sewage treatment plants to learn about the flocculation behavior of water relatively rich in organic chemicals and phosphate. Adding montmorillonite clay to the effluent decreased the turbidity and improved the color of the water. Flocculants used were alum, PVPB, and Purifloc C-31. As a result of the flocculation, clear water was obtained and there were substantial reductions in B.O.D., C.O.D., and concentrations of phosphate and detergents. Relatively large doses were required, evidently because of the presence of organic chemicals and phosphate in the water. (A10-SWC-25)

#### D. Contaminated and Wasted Waters

1. Chemical water contamination. Chemical compounds used by agriculture and industry, as well as those contained in municipal and other wastes, may be potential pollutants to water, soil and air resources. Studies at Watkinsville, Georgia, showed that 2,4-D losses in runoff water from fallow land were positively correlated with soil temperature and the rate of chemical application, were greatest in the initial stages of runoff, and decreased with duration of the runoff period. The iso-octyl and butyl ether ester formulations were more susceptible to removal in washoff than was the amine salt. Losses from 2.2 lbs. per acre were 13 and 4 percent, respectively, for the ester and amine forms. Soil bioassay showed that

most of the 2,4-D remained in the surface 3 inches of soil and did not leach readily into the lower soil horizons.

Other studies show that with normal rainfall the losses of atrazine from 3 lbs. per acre applied to fallow soils would be about 0.06 lb. per acre, or 2 percent of the amount applied. The average concentration in the washoff (water + soil) would be less than 4 p.p.m. These findings suggest that practices to increase infiltration and reduce runoff and erosion will reduce the hazard of such pesticides in water resources originating on agricultural lands.

Preliminary laboratory studies at Baton Rouge, Louisiana, show that endrin can be extracted from soil-water-endrin mixtures. Hexane alone is satisfactory for water-endrin mixtures, but 95:5 mixture of hexane:acetone was required to extract the endrin from the soil. These procedures will be used in future studies of endrin concentration in drainage water from flat sugarcane land. (SWC 4-14(b2))

2. Reclamation of water wasted by phreatophytes. Replacement species of tall wheatgrass and Great Basin wildrye were seeded on a greasewood-rabbit-brush vegetation site in Paradise Valley, Nevada. Successive experimental plot seedings were made in 1961, 1962, 1963 and 1964. All but the fall 1964 seeding received supplemental irrigation to assist seedling establishment. Tall wheatgrass shows the most resistance to the saline-alkali soil conditions. Termination of irrigations on all but the spring 1964 seeding resulted in reduced forage yields. In 1966, practically no forage was produced from plots on which irrigations had been terminated for more than one season. The drastic yield reduction indicates that the phreatophyte replacement species had not developed an extensive root system into the capillary fringe.

It has been found in connection with a study of properties of northern Nevada soils supporting greasewood that greasewood may be responsible for silica cementation in soils underneath the canopy. The soil pH increases to values higher than 9 upon the decomposition of greasewood leaves, which are high in sodium osalate. The high pH can cause a solubilization of solica which, upon leaching, apparently causes cementation. (SWC 4-g1)

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AREA 5: IRRIGATION PRINCIPLES, REQUIREMENTS, PRACTICES  
AND FACILITIES FOR EFFICIENT USE OF WATER ON FARMS

Problem: Competition now faced by irrigated agriculture from municipal and industrial users of water for the limited supplies available is forcing the adoption of improved methods of water application and use. Rigid adherence to historical methods of allocating water has not fostered efficiency. Often water is cheaper than the labor required to achieve more efficient use of water.

Irrigation, historically responsible for the existence of agriculture in the arid West, has become an economic necessity in the production of high-value crops in the humid areas where annual or seasonal droughts jeopardize both the quality and quantity of crops produced.

An estimated 30 million acre-feet of water are lost to the immediate farmer during irrigation application. This consists of losses to evaporation, deep percolation and tailwater runoff.

Improved solutions to many of the problems associated with the irrigation practice, such as use of limited water supplies, methods for efficient water application, optimum time and amount of application in relation to crop growth stage, soil factors, and a practical method of determining when to irrigate, would do much to increase water-use efficiency. Automation in water application has the potential for increasing water-use efficiency while reducing the cost of application. Temperature control by sprinkler irrigation to maintain high crop quality is an area needing further research attention.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in irrigation, utilizing agricultural and hydraulic engineers, soil physicists, and soil scientists at various physiographic area research centers and field stations in the United States. Four PL-480 studies on irrigation are underway in Israel. The scientific and engineering effort in this area totals 19.7 professional man-years. Of this total, 10.6 are devoted to irrigation water requirements, crop response and soil-water relations; 4.9 to water application methods; and 4.2 to systems design for efficient use of water and of labor.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 21 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Irrigation Water Requirements, Crop Response and Soil-Water Relations

1. Water requirements. Accurate determinations of hourly and daily evapotranspiration rates are needed for crops having limited canopy, such as row crops and where alternate furrows are used for irrigation. Instrumentation has been completed at Twin Falls, Idaho, and preliminary data obtained on energy and mass transfer within the soil and plant-air layer. This equipment is completely portable and will enable hourly measurements of evapotranspiration in large irrigated fields. Preliminary data indicate that with low windspeeds in an arid area, net radiation accounts for most of the energy used in evaporating water. For example, determinations of evapotranspiration from an alfalfa field during the latter part of September at Twin Falls, Idaho, indicated that 90 percent of net radiation was utilized in evaporating water and 6 percent was utilized in heating the soil during the period of positive net radiation.

Soil heat flux is one of the components that must be measured when determining evapotranspiration using the energy balance method. Studies conducted at Twin Falls, Idaho, indicate that under some conditions a significant portion of soil heat flow may occur by latent heat transfer involving evaporation-diffusion-condensation processes. Most of the latent heat transfer would not be measured with a common soil heat flux plate. As a result, the net gain or loss in soil heat could be substantially different from the soil heat flux as measured by the plate. These studies indicate that when accurate soil heat flux data are needed, additional measurement may be required.

Measurement of reflectance characteristics of soils and individual plants within the crop canopy is needed in studies of the microclimate and the absorption of solar radiation within the canopy. A small inexpensive reflectometer was developed at Twin Falls, Idaho, for reflectance measurements of intact leaves and soils under field conditions. The instrument is powered by a small battery pack. The observed reflectance characteristics of individual leaves in the range of 0.4 to 1.1 microns as measured with this instrument closely agree with those obtained with expensive laboratory equipment. This equipment will be useful in field studies of the reflectance characteristics of plants as influenced by position within the crop canopy or other factors such as microelement deficiencies. Studies underway are also directed toward establishing a relationship between reflectance and surface soil moisture content, which is desired in many studies involving erosion and evaporation from soil surfaces.

The determination of evapotranspiration by energy balance methods, and the evaluation of the microclimate of plants and plant canopies often require knowing the long-wave emittance of soil and plant surfaces. A new laboratory method, based on the theory of radiative heat transfer between two concentric spheres of different diameters, was developed at Twin Falls, Idaho, for measuring total soil emittance. The method involves solving two simultaneous

transient equations of radiative heat transfer--one representing radiative heat transfer with a material whose surface emittance is known, such as lamp black; and the second representing the radiative heat transfer with a material whose emittance is unknown. The emittance for dry Portneuf silt loam determined using this method is 0.97. Preliminary results indicate that emittance values determined using this method essentially are as accurate as the value for the reference material. (SWC 5-f1)

In the coastal environment of Lompoc, California, there is a very marked trade-off between advection and radiation in the energy exchange processes. On clear summer days, evapotranspiration from irrigated ryegrass accounted for about two-thirds of net radiation. Most of the remaining radiant energy went into heating the air. On partly overcast days, evapotranspiration accounted for nearly nine-tenths of net radiation. On the only very heavily overcast day that was studied, the ratio of evapotranspiration to net radiation was nearly 1.4. On this day negative advection occurred during only a few hours, and positive advection, which took place during the remainder of the day, was more important than on other days. The varying nature of the partitioning of energy which occurred under these conditions suggests that a critical balance between air and surface temperatures resulted in the trade-off.

Potential annual evapotranspiration, computed for eight recent years by the Jensen-Haise formula, varied from 48.7 to 55.8 inches for the vicinity of Lompoc, California. During the year of lowest computed evapotranspiration (1965), there was a reversal of the declining trend of water table elevations in the Lompoc hydrologic subarea. Also in that year, the pumpage for irrigation was the lowest in recent years. It is probable that the low evaporation demand contributed to these situations.

An analysis of three years of records of evaporation from U.S. Weather Bureau type pans at Lompoc, California, showed that in the summer and fall pan evaporation was up to 6 percent greater in a dryland environment than in an area of irrigated ryegrass. The 6-percent difference is much less than has been reported for inland locations. During the rainy season there was essentially no difference in pan evaporation between the irrigated and dryland sites. (SWC 5-9(g2) Rev.)

Evapotranspiration was measured at Reno, Nevada, in connection with a study of minimum water requirements of lawngrass. The 1966 data showed that the average daily lawngrass evapotranspiration on a twice weekly irrigation schedule was 0.22 inch per day for a loam soil and 0.21 inch per day for a sandy loam soil. The average daily evapotranspiration for 7-day irrigations was 0.21 and 0.20 inch per day for the loam and sandy loam soils, respectively. These observations are in general agreement with measurements made in the two preceding years. The pan evaporation, net radiation, Olivier, and Penman methods can be used to estimate lawngrass evapotranspiration with comparable accuracy on a monthly or seasonal basis. However, none of the methods adequately predicts peak water requirement periods for lawngrass. (SWC 5-9(g2) Rev.)

2. Scheduling irrigation applications. Scheduling irrigation to use water most efficiently and to obtain optimum yields has been a problem long plaguing the irrigation farmer. Various devices such as soil moisture blocks, tensiometers, and methods involving manually sampling the soil to determine its water content have been used. If evapotranspiration can be estimated daily using available climatic data and predicted several days in advance using weather forecasts, then more efficient irrigation water management and net returns to the farmer are possible. Studies conducted at Twin Falls, Idaho, in 1966 indicate that all irrigations throughout the season can be scheduled using climatological data, precipitation, and stage of growth characteristics. The yield of sugar beets was 24.8 tons per acre on a treatment where all irrigations were based on climatological data as compared to 25.0 and 25.5 tons on two other treatments that were irrigated according to prescribed soil moisture levels. The sugar yield on this treatment was 4.2 tons per acre as compared to 4.3 on the other two treatments. This study will be expanded in 1967 to several other crops and to farm fields with cooperators irrigating according to predicted water requirements. Predicting irrigations will also involve a study being initiated in cooperation with the U.S. Weather Bureau to utilize 3- to 5-day forecasts of climatological conditions, thus permitting the scheduling of irrigations 3 to 5 days in advance. (SWC 5-fl)

In a PL-480 study in Israel to determine the effect of the moisture factor on stomatal aperture and its influence on rates of transpiration and photosynthesis three methods have been tested as indicators for timing of irrigation applications. Of the three, silicon rubber impressions, infiltration and the field parameter, the latter method appeared the most suitable. It was also shown that for corn the measurement should be carried out between 9:30 and 11:30 a.m. on cloudless days. This was due to the inability of the corn to maintain maximum stomatal openings during noon hours and in the early afternoon. Leaf permeability determined with a field parameter furnishes a measure of stomatal aperture. (A10-SWC-29)

3. Crop response to water, fertilizer and other management practices for efficient use of water. Forage yields and water-use efficiency of Coastal bermudagrass at Watkinsville, Georgia, were increased by irrigation, high nitrogen level, and longer time between clippings in 1966. Yields in tons per acre on a dry-weight basis with and without irrigation were 1.9 and 1.1, 4.5 and 2.5, and 5.2 and 2.6 for N-K levels of 200-100, 600-300 and 1000-500 lbs. per acre, respectively, when clipped at 2-week intervals. Clipping at intervals of 4 weeks increased yields to 3.4 and 1.8, 6.6 and 3.9, and 7.0 and 4.1, respectively, with and without irrigation and the three N-K levels. Yields when clipped at 6-week intervals were 6.5 and 3.8, 8.9 and 5.6, and 8.9 and 6.2 for these same irrigation and fertility treatments. The inches of water used per ton of forage produced for irrigated versus not irrigated at the three fertility levels noted above were 6.9 and 10.1, 2.7 and 4.2, and 2.3 and 3.8 for the 2-week clipping frequency; 3.9 and 5.9, 1.8 and 2.5, and 1.4 and 2.3 for the 4-week clipping frequency; and 1.8 and 2.8, 1.4 and 1.9, and 1.3 and 1.6 for the 6-week clipping frequency. (SWC 5-bl)

Analysis of cotton fiber quality at Thorsby, Alabama, showed that both surface irrigation and fogging of plants to reduce foliar temperature tended to reduce the fiber uniformity ratio, length, strength and micronaire, and lint percentage. The fiber elongation ratio was increased slightly, however. These treatments were applied under conditions of near-normal rainfall when the cotton did not suffer soil moisture stress. Previous studies have shown that irrigation to relieve soil moisture stress has beneficially affected cotton fiber. (SWC 5-b1)

The yields of six corn hybrids were related to germ plasm potential, plant population and available water supply on Cecil sandy loam at Watkinsville, Georgia. The top-yielding hybrid produced 152 and 142 bu./acre for 26,000 and 13,000 plants per acre, respectively, with irrigation. Without irrigation the yields were 54 and 88 bu./acre, indicating that water must be adequate for optimum yields at the higher population for this hybrid. The lowest yielding hybrid produced 110 and 120 bu./acre for 26,000 versus 13,000 plants per acre with irrigation, and 20 and 41 bu./acre for the same populations without irrigation. The higher population of this hybrid reduced yield with or without irrigation. (SWC 5-b1)

Seeding and fertilization offer a practical solution for improving high-elevation mountain meadow hay production in Wyoming. Encroachment of introduced grasses, namely, Garrison creeping foxtail, reed canarygrass, and common meadow foxtail, into a native mountain meadow grass sward was striking under both irrigated and high water table conditions. Round plots (3 feet in diameter) seeded in 1963 to Garrison creeping foxtail now average as much as 5 to 6 feet in diameter for three nitrogen rates where as much as 11 feet of water has passed through the soil profile under continuous irrigation. Yields for all introduced grasses under investigation were 4- to 6-fold higher than those nonfertilized native species (0.7 to 0.9 ton per acre) for both high water table and continuous irrigation treatments. Established introduced grasses fertilized with N are producing more forage than grass-legume mixtures or legumes fertilized with 0 or 88 pounds of phosphorus per acre. (SWC 4-d1)

The potential yield of sugar beets is reduced about one ton for each week that germination is delayed in the spring. Use of a 3-inch strip of clear plastic over the seed row to increase soil temperatures and accelerate germination on irrigated land at Carrington, North Dakota, failed to produce significant differences in root or sugar yield. Use of bedding techniques to trap solar radiation likewise offered no advantage in extending the growing season or maximizing yield by earlier germination of seed. (SWC 5-d1)

Limited irrigation of winter wheat may permit more efficient use of limited water resources for irrigation of more than one million acres of winter wheat in the Southern Plains. Highest winter wheat yields, per unit of water used, were attained when irrigation water was applied during heading through early grain development at Bushland, Texas. Maximum response to water application in level basins was 11.5 bushels per acre from a 4-inch irrigation at heading, which resulted in a water application efficiency of 2.9 bushels per acre-inch

applied. When four spring irrigations were applied to produce high yields, the efficiency of applied water dropped to 2.1 bushels per acre-inch. When water was applied during early spring only (in a dry spring) efficiency of applied water dropped to about 0.5 bushel per acre-inch. Moderate soil moisture stress during early spring did not affect yields appreciably if adequate soil moisture was available during the critical period of heading through grain filling.

Growing a winter and summer crop in alternating 80-inch strips increased summer crop yields and used limited water supplies more efficiently than conventional cropping systems in the Southern Plains at Bushland, Texas. Continuous grain sorghum grown in 80-inch double-bed strips alternated with winter wheat produced 16 percent (940 lbs. per acre) more grain than solid-planted grain sorghum, when both received adequate irrigation. Yields of grain sorghum grown under limited irrigation in alternate double-bed strips equaled yields from solid-planted sorghum grown under adequate irrigation. Fewer irrigations and less irrigation water were required by sorghum grown in 80-inch strips alternated with wheat. (SWC 5-5(el) Rev.)

Irrigation water management studies were conducted at Twin Falls, Idaho, as a part of large-scale study to assess the suitability of this area for economic production of safflower oil. Maximum grain and oil yields were obtained when the soil moisture tension was allowed to approach 9 atmospheres at the 18-inch depth before irrigation. More frequent irrigations resulted in about 7 percent more seed heads per foot of row, but the total weight of grain harvested was less. Grain yields ranged from 3,700 to 4,000 pounds per acre with an oil content of about 37 percent. The results obtained from farm fields indicate that the oil content is greatest with the largest yields. Evapotranspiration for safflower was approximately 26 acre-inches in 1966. (SWC 5-fl)

Establishment of stands for crops having small seeds, such as sugar beets, lettuce, etc., is often hampered in arid areas by the drying of the seedbed before germination and emergence are completed. At Twin Falls, Idaho, studies have been conducted on dropping the seeds in small holes punched in the soil. These holes do not need to be backfilled. The soil moisture content at the seed level remains high long enough to permit germination. Also, because the holes are open, seedling emergence is not restricted by the soil crust that often forms over surface planted seed. The open-hole punch method of seeding has additional advantages--maximum temperatures at the seed level are low, salt content adjacent to the seed is lower, and initial tillage and irrigation requirements may be reduced. (SWC 5-fl)

Crusting of surface soils following intense rains is a common problem in arid areas. One possible technique for minimizing the effects of the crust is planting orientation of large seeds such as beans. In greenhouse studies conducted at Twin Falls, Idaho, beans planted with the hypocotyl end downward required more time to emerge and the percentage of plants emerging was less than beans planted with the hypocotyl end upwards or in the conventional

lay-flat orientation. These studies indicate that planting equipment designed for spaced plantings may require consideration of the geometric orientation of the seed to assure maximum emergence. (SWC 5-fl)

4. Water intake, transmission, storage and deep percolation. Water extraction from the soil may be increased by altering the soil profile to increase root proliferation or depth of rooting, thereby lessening the need for irrigation in the South. Studies on Norfolk sandy loam at Florence, South Carolina, showed that cotton roots penetrated deeper into the soil profile, with greater proliferation, where the A<sub>2</sub> and part of the B horizon of the soil was mixed with the A<sub>p</sub> horizon. Of the 7.2 and 14.2 gm. of roots contained in the 5-foot depth, 94 and 77 percent were located in the 0- to 15-inch depth for the treatments plowed 8 inches and mixed 18 inches deep, respectively. More water was extracted and plants suffered less from moisture stress where the deeper soil layers were mixed with the top layer. (SWC 5-bl)

Deep moldboard plowing Pullman silty clay loam soil increased grain sorghum yields under limited irrigation at Bushland, Texas. With one irrigation, yields ranged from 3,420 pounds per acre with 8-inch-deep plowing to 5,200 pounds per acre with 32-inch-deep plowing. When two irrigations were applied, yields ranged from 5,020 pounds per acre with 8-inch-deep plowing to 6,340 pounds per acre with 16-inch-deep plowing. Plowing 24 or 32 inches deep increased yields slightly under the higher irrigation level. Yield increases are believed to result from increased storage of available soil moisture after plowing this slowly permeable soil, which has a root-restricting B horizon. (SWC 5-5(el) Rev.)

Measurements at Thorsby, Alabama, show that significant amounts of water are lost by deep drainage from the root zone after saturating the profile of Coastal Plains soils. The rate of drainage declines with time, however. The quantity of water drained from the 0- to 48-inch layer of Ruston, Greenville, and Faceville sandy loams, respectively, totaled 2.27, 1.30, and 1.12 inches the first three days. The average daily rate was 0.023, 0.025, and 0.032 from the eighth to the thirty-seventh day. These drainage rates show that evapotranspiration rates computed from changes in soil water content must take into account the rate of water loss by deep drainage from the root zone. (SWC 5-bl)

Direct measurement of soil water flux in unsaturated soils is highly desired in many field experiments and hydrologic studies. A soil-water flux meter for direct determination of this important parameter has been developed at Twin Falls, Idaho. This instrument operates on the same principle as soil-heat flux transducers. Preliminary results indicate that the instrument is relatively insensitive to hysteresis, changes in bulk density, and salinity, all of which may change unsaturated hydraulic conductivity of soil by a factor of 2. The primary disadvantage of the instrument is that it will operate only in the tensiometer range. However, the bulk of unsaturated flow, such as deep percolation below the root zone of an irrigated crop or upward movement from a water table, takes place within this range. (SWC 5-fl)

Infiltration rates with furrow irrigation are extremely low in many of the irrigated areas of the Western United States. The infiltration rates in the Columbia Basin area may average 0.16 inch per hour in mid-June but may decrease to 0.05 inch per hour in mid-August. Under these conditions, the total intake in 24 hours is about 1.2 inches. With evapotranspiration rates of about 0.25 inch per day, 24-hour irrigations once a week would not supply adequate water to meet evapotranspiration requirements. A significant portion of the decrease in intake rate appears to be related to a vesicular structure that forms immediately below the furrows. Studies are currently underway at Prosser, Washington, to control infiltration rates on these soils by incorporating plant residues and by the use of cultivation and controlled soil moisture levels prior to irrigations. (SWC 5-fl)

## B. Water Application Methods

1. Surface irrigation techniques, hydraulics and water infiltration. A recirculating furrow infiltrometer has been developed and tested at Twin Falls, Idaho. Water is applied to individual furrows through small diameter orifices in the side of a 4-inch-diameter aluminum distribution pipe. A collection channel is placed across the lower end of the plot area where the runoff water is collected and returned to the water storage reservoir. The volume of water that enters the soil during an irrigation interval is volumetrically determined by the changes in water level in the reservoir tank which is recorded automatically. (SWC 5-fl)

Numerous studies have been conducted on the advance of water in irrigation borders or furrows, but only limited studies have been conducted on the recession of water. Some approximations of the time required for recession to begin at the upper end assume that the water surface approaches a horizontal position after inflow has stopped. Studies on uniformly graded borders at Twin Falls, Idaho, indicate that the slope of the water surface remains nearly parallel to the soil surface during recession. Simple approximate solutions to recession time are now possible when flow velocity-depth relationships are completed. (SWC 5-f2)

Studies at Logan, Utah, show that the maximum range of discharge flows for a siphon tube occurs when the centers of the intake and discharge openings are at the same elevation. When the siphon is discharging in the air, raising the outlet end reduces the discharge rate and lowering the discharge end increases the flow rate. The shape of the siphon tube influences the range of available flow rates. Plotted curves of test data showing maximum and minimum discharges for various angles can be used to select siphons for greatest flexibility of use. (SWC 5-8(gl) Rev.)

2. Sprinkler irrigation techniques, equipment and water distribution. Cooperative studies with Colorado State University, Fort Collins, Colorado, to formulate and solve mathematical expressions for application depths and rates by computer techniques has facilitated procedures to properly design the center pivot, self-propelled sprinkler irrigation system capable of irrigating about 1/4 section of land in one circle. Mathematical equations

developed can predict the distribution of water application depth for a given nozzle discharge and pattern radius for the sprinkler nozzle in question. The computer program also provides an analysis of application rate vs. time in relation to actual intake rate vs. time, thus permitting a rapid assessment of performance characteristics of design parameters indicated above. (SWC 5-d1)

In a PL-480 project in Israel to determine the effect of low intensity sprinkler irrigation (4.5 mm. per hour) in comparison to high intensity (18 mm. per hour) on soils, plants, salinity and water use, the bulk density of the surface layer in gm. per cm.<sup>3</sup> was found to be 1.24 with the low and 1.33 with the high intensity. Yield of celery and parsley was greater with the low intensity although some of the difference may have been due to differences in water absorption. The high intensity exceeded the infiltration rate of the soil. (A10-SWC-19)

3. Subsurface irrigation techniques and equipment. Porous tile used for subirrigation of Tifway bermudagrass on Arzel fine sand at Fort Lauderdale, Florida, performed satisfactorily when the water was treated with hydroxyacetic acid to dissolve inorganic deposits and with sodium hypochlorite to prevent bacterial growth in the tile. Flow of water through the tile walls was dependent on pressure head and degree of clogging in the tile pores instead of the capillary tension of the soil. Vigor of the sod indicated that water was utilized effectively about 1 foot laterally from the tile, suggesting that 24-inch spacing will be required for effective water distribution. Placing organic soil, crushed rock or plastic sheeting beneath the tile had no effect on the flow rate through the tile. These materials interrupted the downward movement of water, however, and increased the effectiveness of the tile. Roots were observed to be matted around the tile, in the organic layer and the crushed stone, and on the plastic sheet, indicating areas of available soil water. (SWC 5-b1)

Newly planted citrus trees at Riverside, California, have now been grown for three seasons with subsurface irrigation. Full-grown trees irrigated by subsurface application methods produced as well as trees that received surface irrigation. Amounts of water applied by subsurface methods were generally less than by conventional irrigation methods. (SWC 5-8(gl) Rev.)

#### C. Systems Design for Efficient Use of Water and of Labor

1. Irrigation systems efficiency. Maximum retention and storage of winter precipitation in the soil can be a significant economic factor in gently sloping pump-irrigated areas, and in assessing irrigation water requirements of farms or projects. Studies at Twin Falls, Idaho, have shown that the increase in soil water content as a result of overwinter precipitation can be closely approximated if the maximum water-holding capacity, the water content in the fall, and total overwinter precipitation are known. The estimating equation also clearly indicates the importance of allowing soil moisture levels to be depleted in the fall if maximum retention of precipitation is desired. (SWC 5-f2)

2. Automation. Field testing is the final stage in the development of automatic and semiautomatic water control devices for surface irrigation systems. At Twin Falls, Idaho, most of the difficulties encountered with semiautomatic structures in 1966 were associated with the timers used. A redesigned timer unit with a built-in escapement release and a factory-sealed enclosure is expected to alleviate this major problem. Uniform water distribution to furrows or corrugations is also a problem if the water contains trash. Sheet metal cutoff walls with 90° V-notch openings did not clog as compared to small spiles, and floating trash generally passed without difficulty. All types of furrow regulators obstruct cleaning operations in unlined ditches. Lined ditches alleviate much of these problems. Semiautomatic structures installed in 2,600 feet of a lined ditch (for 50 acres) designed for cutback operation near Ault, Colorado, performed satisfactorily. An additional 3,000 feet (for 90 acres) will be installed in 1967. If this system were installed on the entire 540-acre farm, it is estimated that one man could irrigate alone with time to spare for other operations. A minimum of two full-time irrigators with some additional labor for night irrigating are now required. Tests at Twin Falls, Idaho, have indicated that water application efficiencies of 80 percent can be achieved with an automatic cutback furrow irrigation system. (SWC 5-f2)

Further progress in development and evaluation of devices for automation of surface irrigation distribution systems, including both open ditches and buried concrete pipelines, made through investigations directed from Fort Collins, Colorado, include the following:

At Wiggins, Colorado, 78 acres cropped to field beans, corn and sugar beets were automatically furrow-irrigated by the farmer, utilizing pneumatic O-rings (see 1965 multipurpose report) and improved remote telemetry controls and timer. Fail-safe features were incorporated to turn the pump off when the last automatically timed valve had closed or in case of a malfunction in the automatic system. The Agricultural Research Service has been awarded a patent for the pneumatic valve used in this system. (SWC 5-d1)

On Maui, Hawaii, 13.4 acres of sugarcane have been automated on an experimental basis, utilizing water-powered hydraulic cylinders to operate gates in an open-ditch distribution system. Driving a water piston in response to a float-controlled bleeder valve was made possible by combining a 4-way plastic hydraulic valve from commercially available single valves used to automatically irrigate lawns and turf grass. The 4-way valve and float-controlled bleeder valve form the "heart" of the automatic irrigation control. It permits modulation of gates to maintain a constant depth of water either upstream or downstream from the control gate in the distribution ditch. Present techniques utilizing electronic gear, batteries, soil-water sensors, etc., to override the hydraulic controls when sufficient water has been applied appear too costly and impractical. Present laboratory developments will permit modifications to achieve automation with complete hydraulic control. Furthermore, gates now using large water pistons ( $2\frac{1}{2}$ " diameter and 18" stroke) have been operated with a piston only  $1\frac{1}{8}$ " in diameter and 6"

stroke using an improved gate design. These modifications should substantially reduce cost of system control and provide for complete automatic operation. (SWC 5-d1)

At Fontanelle, Wyoming, lay-flat pneumatic butyl rubber valves in farm turnouts were less successful than the O-ring type with inner tubes. Damage encountered from rodents and from natural cracking of the nylon-reinforced butyl rubber had to be periodically repaired to prevent air leaks. More recent developments that utilize complete hydraulic controls and piston-operated gates are expected to replace the inflatable rubber valves. (SWC 5-d1)

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AREA 6: DRAINAGE PRINCIPLES, REQUIREMENTS, PRACTICES,  
AND FACILITIES FOR PROTECTION OF CROPS AND SOILS

Problem: Excess water is the dominant hazard to 245,600,000 acres or 17 percent of the land in the United States. For the cropland area, excess water is the dominant problem on 59,908,000 acres or 14 percent. Water management systems have been applied to some 140,000,000 acres of potentially wetland in the United States. More than 90,000,000 acres are in organized districts and the remainder are individual farm enterprises. More than 60 percent of the acreage in organized districts and the remainder are individual farm enterprises. More than 60 percent of the acreage in organized districts is in seven Corn Belt States. The U.S. Census Report for 1960 shows an expenditure from 1950-60 for new drainage work of nearly \$186,000,000 and a cost of maintenance, operation, and repair of more than \$231,000,000.

There are numerous water management problems on agricultural lands. High water tables during the spring restrict root development, which lowers the plants' drought resistance during the dry periods that generally follow. Water ponded in microtopographic depressions delays plantings beyond optimum dates, and makes the use of modern high-speed farming equipment uneconomical. Hillside seep areas function similarly to reduce farming efficiency. Conventional methods of subsurface drainage are costly. Drainage design is generally based on empirically determined drainage coefficients instead of precisely developed drainage or aeration requirements of specific crops.

The economic success and feasibility of many irrigation projects depend on adequate subsurface drainage to prevent salting out and abandonment of the projects. On more than 50 percent of the irrigated acreage in the 17 Western States, or more than 15,000,000 acres, drainage is a necessary complement for successful operation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of land drainage, utilizing agricultural and hydraulic engineers, soil physicists, and plant physiologists at various physiographic area research centers and field stations throughout the United States. The scientific and engineering effort in this area totals 20.9 professional man-years. Of this total, 2.1 are devoted to surface and open ditch drainage; 5.4 to subsurface conduit drainage; 2.1 to drainage for salinity control and reclamation; and 11.3 to design of optimum drainage systems.

## PROGRAM OF STATE EXPERIMENT STATIONS

A total of 17 scientific man-years is devoted to this area of research.

### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

#### A. Surface and Open Ditch Drainage

1. Land forming, cut and fill effects and remedial measures. Land graded in 1961 to slopes of 0.10, 0.15, 0.20, and 0.25 feet per 100 feet on Mhoon and Commerce silt loam at Baton Rouge, Louisiana, was tilled regularly and reshaped each year for corn harvested as silage. A resurvey in late 1966 showed the average slopes to be 0.11, 0.16, 0.19, and 0.26, respectively. Determinations of the land elevation throughout the areas showed a slight lowering of the land surface at the edge and end, with a corresponding increase in elevation near the center, of each treated area. This was the result of the land leveler action while resmoothing the fields each year. Fields with land slopes of 0.15 and less need reshaping at least each 2 years for good surface drainage. This maintenance is not as critical where row grades are greater, and especially where row ridges are high. (SWC 6-b2)

2. Row grade and length effects. Data obtained from the row grade and length study at Baton Route, Louisiana, were used to develop prediction equations for peak rates and total amounts of runoff. The parameters in the prediction equations were rainfall intensity (I), land slope (S), slope length (L), and soil moisture deficit (M). The soil moisture deficit was obtained by subtracting  $0.8 \times$  measured pan evaporation from the soil water content each day. Rainfall intensity that best fitted these conditions was the maximum 35-minute intensity in each rainstorm. Land slopes were 0.10, 0.15, 0.20, and 0.25 feet per 100 feet, and slope lengths were 500, 700, 900, and 1100 feet. Formulas derived through multiple regression techniques were:

$$\text{Peak runoff rate} = 0.02 + I (0.56 + 1.92S - 0.00043L) - 0.15M$$

$$\text{Amount of runoff} = 0.09 + I (0.34 + 0.90S - 0.00017L) - 0.14M$$

Studies are continuing to determine if nonlinear equations give better predictions and to determine the effect of row shape, cropping treatment and other factors on rates and amounts of runoff. (SWC 6-b2)

#### B. Subsurface Conduit Drainage

1. New materials--laboratory and field tests of performance. The amount of plastic material used in the manufacture of plastic drainage pipe is a principal factor governing its cost. At Columbus, Ohio, the factors of greatest significance for designing plastic drains have been identified and a method, which utilizes a computer program, has been developed for using these factors in designing plastic drain tubes. This procedure,

for specified soil-loading requirements, makes possible the prediction of designs that give the required strength at minimum cost. Corrugation of the tubing wall is a principal technique used to increase strength per unit weight of material. Both laboratory tests and field results have compared favorably with theoretical predictions. Evaluation and tests of smooth-walled plastic pipe installed in an Iowa field also compared favorably with the theoretical calculations. (SWC 6-cl)

At Weslaco, Texas, the Manning "n" value (retardance coefficient) was determined on a section of 4-inch I.D. plastic pipe with 2-1/2 corrugations of 1/4-inch depth per inch. Under full pipe flow, Manning's "n" was 0.015 for flow rate between 10 and 70 g.p.m. as compared to the commonly used design value of 0.011 for clay tile. (SWC 6-12(e3))

Studies of flow from an aquifer to drain tile joints through a gravel envelope at Fort Collins, Colorado, indicate that low gravel permeabilities may restrict the flow. Low permeabilities become more restrictive as the spacing of tile joints is increased. These findings verify, qualitatively a theoretical analysis made by the U.S. Bureau of Reclamation. Upper portions of the gravel envelope may not be under positive pressures. If the capillary rise in the envelope gravel is small and if the gravel becomes vented to the atmosphere, portions of the envelope will desaturate, reducing the "effective pathways" available to transmit water flow to the tile joints.

A unique physical model has been constructed for investigating drainage systems so that the partially saturated region above the water table may be studied. Preliminary findings for the drainage of soil between equally spaced ditches indicate that the water table falls faster during early stages of drainage than the saturated flow theory predicts. Drainage out-flow from the ditches, however, occurs more slowly than present theories predict. (SWC 6-d1)

2. Installation equipment and techniques. With the new mole plow method of installing flexible corrugated plastic drain pipe, grade control is an essential element for system installation and performance. The groundspeed of this drain installation machine is so rapid that the present methods of grade control are entirely inadequate. A laser-beam automatic grade control system which provides for accurate grade control on both conventional and high-speed drainage equipment has been developed and successfully tested at Columbus, Ohio. This system utilizes a portable, but stationary, low-power laser-beam as an elevation reference, and an electronic machine-mounted detector device, which automatically operates the hydraulic depth-regulation mechanism. In field trials, this system corrected for all vertical deviations greater than 3/8-inch from the desired drain grade. Tests have been made for distances only up to 1500 feet, but comparable control is anticipated over even greater distances. This control system in combination with newly developed corrugated plastic pipe now makes it possible to rapidly and accurately install subsurface drain at greatly reduced cost. The system will have further application in agriculture for land leveling,

ditch construction, etc. It can also be applied to civil engineering and military construction projects to speed up operations and minimize labor and other costs where grade control of earth-moving equipment is required. (SWC 6-cl)

3. Chemical and biological clogging of tile. At Brawley, California, in research on the processes of tile clogging by iron and manganese oxides it was found that the redox potentials of soils at tile depth of 8 feet and deeper remained continuously low throughout the irrigation season until December. The potentials above tile depths of 5 feet fluctuated more widely than at the lower depth, probably because periodic drying permitted the entry of air into the soil profile. Ground water generally had less than 1 p.p.m. of  $\text{NO}_2$  and  $\text{SO}_3$ . In one set of samples  $\text{H}_2\text{S}$  varied from 3 to 20 p.p.m.  $\text{SO}_3$  in tile effluents was markedly higher than in ground water. With knowledge of the processes by which the chemical and biological clogging of tile occurs, prevention practices may be developed. (SWC 6-g2)

#### C. Drainage for Salinity Control and Reclamation

Utilizing accumulated data on inputs of water and salt by irrigation and outputs of water and salt as drainage, salt and water balance conditions in the irrigated land of Coachella Valley, California, for the period 1957-1962 were studied at Riverside, California, in cooperation with the Coachella Valley County Water District. The salt balance index (output of salt/input of salt) was highly related to both the area of irrigated land having tile drainage and the leaching percentage. The index became one in 1963 when about half the irrigated land was tiled and the leaching percentage increased to about 30. As the theoretical leaching requirement was found by calculation to be 20 percent, the amount of additional leaching needed to compensate for nonuniformity of water application and infiltration was 10 percent. At salt balance, measured values of leaching and values for evapotranspiration, taken as the difference between applied and drained water, agreed closely with the values calculated by equations previously proposed by the U.S. Salinity Laboratory. Use of these equations requires knowledge of the depth of irrigation water applied and the salt concentrations of irrigation and drainage waters only. The study confirms the validity of previously proposed theory for salinity control including the concepts of salt balance and leaching requirement, and provides increased confidence in the application of the theory to practical salinity problems. (SWC 6-gF1)

At Brawley, California, the performance of a tile system installed in 1952 and known to contain manganese oxide mineral deposits, which impede the entry of drain water, was compared with an identical system installed in 1964 midway between the older lines. The new system removed more than twice the water and about four times the salt than did the old system. (SWC 6-g2)

Research on reclamation of a salt-affected soil at Brawley, California, has shown that use of drain tile as underground conduits to saturate the stratified alluvial soil profile speeds removal of salts. The procedure is practical on this soil since deep percolation losses are relatively small. The tile line is plugged at the outlet and irrigation water introduced at the upper end to speed saturation of the profile. With a leaching percentage of 23, the removal of salts amounted to 30 percent in the 0- to 6-foot soil profile. This soil's slow water intake during surface flooding limits effectiveness of conventional leaching. (SWC 6-g2)

Laboratory model studies of electro-osmosis were conducted at Brawley, California, to determine the feasibility of using this technique in field leaching and salinity reclamation. It was found that the minimum power requirement for electro-osmosis in the field is still too high to be economically feasible. However, the technique might be used to reclaim small, difficult, "slick spots" in fields that are otherwise relatively salt free. (SWC 6-g2)

Drainage investigations were initiated on an irrigation project in southern Idaho where high water table conditions have existed since the project was first irrigated in 1905. The irrigation water on the project is very low in soluble salt and, even with the high water tables, saline soil problems now occur on only about 5 percent of the project. Water table changes during the cropping season today do not differ significantly from observations made in 1914 and 1930, even though a number of surface drains have been installed. A detailed study of a saline area indicates that saline soils now exist where the water table rises to less than 5 feet from the surface during the irrigation season. Complicating factors that hamper major changes are unlined canals, lack of water-measuring structures and many farm operators who through custom, rely on high water tables for subirrigation. Measurements currently are underway to obtain sufficient data to permit a numerical analysis of the disposition of water within this project, delineating such items as natural drainage, evapotranspiration, and surface drainage from which control measures that will be required to maintain water table levels below 5 feet in the problem areas can be formulated. (SWC 5-f1)

#### D. Design of Optimum Drainage Systems

1. Drainage requirements for plants and tillage. Drainage involves the removal of excess water from a depth of soil in order that a satisfactory environment for root growth and function may be provided. To provide drainage design criteria, it is necessary to define this environment and to predict plant performance when excess water is removed.

At Raleigh, North Carolina, the root systems of different plant species have been exposed to different gaseous environments while being sprayed

periodically with a nutrient solution mist spray. *Ficia fava* (horse bean) primary root tips and about 30 percent of the secondary root tips were nearly always killed by a 24-hour pure nitrogen gaseous root environment. Rate of cell division and growth of the undamaged roots resumed, however, when exposed to air. Use of 1 percent of oxygen with nitrogen reduced rate of cell division by 80 percent but complete recovery occurred in 6 hours in air with no permanent damage. A 24-hour exposure of roots to mixtures of oxygen and carbon dioxide containing more than 6 percent carbon dioxide killed a high percentage of the secondary roots but seldom damaged the primary root. The root primordia within the primary root do not appear to be damaged seriously when as much as 1 percent oxygen is present, even in the presence of 20 percent carbon dioxide. Tobacco roots in contrast to those of horse bean did not seem to be damaged by 20 percent carbon dioxide as long as 2.5 percent oxygen was present. Thus, certain species are sensitive to carbon dioxide concentration with a less critical oxygen requirement whereas others have an opposite requirement.

Other experiments at Raleigh, North Carolina, using intact tobacco root systems as above have shown that contrary to previous observations, oxygen uptake by the roots shows no diurnal variation. The contrary observation of others, it appears, was a product of diurnal temperature variation. It also has been shown that oxygen uptake is the same in light and darkness and is unaffected by rate of transpiration. It has also been observed that reduced water uptake associated with decreased oxygen level may be caused by stomatal closure rather than root aeration.

In sheltered lysimeter experiments at Raleigh, North Carolina, water table levels have been maintained at several stated depths and yield response of several crops determined when only subsurface watering was permitted and when additional surface watering was done. It is concluded that the optimum water table depth for maximum yield is very significantly affected by the surface watering. (SWC 6-b1)

Investigations at Grand Junction, Colorado, have shown that air porosity requirements for germination of corn seeds and subsequent root elongation are considerably greater in coarse, loose soil than in fine, compact soil. Air porosity must be greater in the former case because seeds can be covered with water even when most of the soil is well drained, and tissue hydration is greater at equivalent porosities. Theoretical equations adequately describe diffusion of  $O_2$  through wet soils regardless of aggregate size or soil density. Diffusivity of  $O_2$  in soil is a unique function of air porosity. (SWC 6-d1)

Claims have been made that N fertilization can alleviate the effects of poor drainage to some degree. Studies were conducted in 1965 at Norfolk, Virginia, in which corn was grown in the greenhouse using 0, 100 and 200 lbs. of N per acre as  $NaNO_3$  and  $(HN_4)_2SO_4$  at each of three soil water

conditions: field capacity, water table at the 6-inch depth, and at the 2-inch depth. N fertilization with  $(\text{HN}_4)_2\text{SO}_4$  increased yields at high soil water levels but fertilization with  $\text{NaNO}_3$  decreased yields. In 1966 the same treatments were used for tomatoes grown on the same soil, Elkton silt loam, and in addition both corn and tomatoes were grown on a Rumford loamy fine sand. Results in 1966 generally indicated that yields were greatly reduced by excessive wetness and that N fertilization did not alleviate the condition regardless of the form applied. (SWC 6-a1)

2. Soil properties, hydraulic conductivity and other factors related to drainage. In designing drainage systems, formulas are used which are based upon idealized conditions. One such condition that is commonly assumed in the development of drainage equations is that the soil is uniform and homogeneous with regard to permeability. Because of extreme variability in soils it is very difficult to evaluate permeability by field tests for use in these equations. At Morris, Minnesota, in controlled drainage experiments, soil permeability was measured by the field piezometer method. These values compared very favorably with calculated values using measured tile outflow rates and rate of lowering the water table in the van Schilfgaarde equation. These results give confidence in the field methods of determining permeability for drainage design. (SWC 6-c1)

Hydraulic conductivity rates were determined at Fleming, Georgia, on each horizon of the 13 important soil series, totaling 102 measurements, in the Atlantic Coast Flatwoods land resource area. Tests made in the center of each horizon ranged in depth from 1 to 45 inches below the soil surface. Rates of water transmission through these horizons varied from 0.002 foot per day on Charleston fine sandy loam and Fairhope sandy clay to 6.96 feet per day on Leon fine sand. There was no consistent relationship between hydraulic conductivity and sand sizes or amount of sand, silt or clay in the soil. A restrictive horizon with low hydraulic conductivity occurred in all soil series tested. This barrier largely controls the movement of water through the soil when it is above the water table. The hydraulic conductivity values indicate that only the Irvington, Kiawah, Lakeland and Leon series have adequate internal drainage characteristics. The low rate of water movement in the other 9 series (Charleston, Dunbar, Edisto, Eulonia, Fairhope, Goldsboro, Klej, Lynchburg and Weston) suggests that surface drainage systems are necessary for removal of excess water from rains of large volume and high intensity in this area. (SWC 6-b2)

At Reno, Nevada, in-place hydraulic conductivity measurements of the aquiclude were made at 164 sites, all on a single soil mapping unit. The results show extreme range of auger-hole permeabilities, from 0.21 to 184 inches per day. This partially explains the irregular fluctuation in the water table during the irrigation season. It also indicates the futility of obtaining meaningful and consistent measurements of hydraulic conductivity on such soils by the auger-hole method. (SWC 6-g2)

Studies at Burlington, Vermont, are designed to evaluate temperature effects on soil water flow, specifically in regard to freezing and thawing. Results using freely drained 10-inch columns of coarse and fine sand, with surface temperatures maintained at 22-25° F., showed marked insulating qualities. Establishment of a water table within the column resulted in ice lens formation. Preliminary results suggest that under field conditions a well-drained soil will act as a partial insulator, slowing the development of ice and maintaining a higher infiltration rate. (SWC 6-a1)

3. Systems performance--flat and sloping lands. At Belle Glade, Florida, plastic lined mole drains were compared with conventional mole drains and no moles in an organic soil. A thin layer of marl between the organic soil and rock substrate existed. Lowering the water level in the drain ditch 18 inches in 9 hours lowered the water table in the plastic lined mole plot 15 inches in 20 hours (3/4 in./hr. on average), whereas 56 hours were required for the conventional and no-mole plots. Where no marl exists, a period of 33 hours has been observed for a similar water table lowering. This points up the importance of describing the physical characteristics of rock and soil material beneath the organic soil in which water regulation is contemplated. (SWC 6-b1)

Evaluation of surface and subsurface drains, alone and in combination, on a Cabot silt loam at East Franklin, Vermont, continues to indicate the necessity of subsurface drainage for adequate water removal. Climatic conditions were such that winterkilling destroyed almost the entire stand of alfalfa on all treatments except the one that provided maximum drainage (diversion terrace plus subsurface drains at 100-foot spacing). On this treatment there was at least 50 percent survival. Loss of alfalfa stand was attributed to two factors resulting from poor drainage: heaving of the crowns and incidence of crown rot. Results indicated that drainage to a soil water content equivalent to 0.1 bar tension will minimize this hazard. During 1966, drainage treatment efficiency was reflected in total drain discharge volume. These data again show the greater efficiency of subsurface drains as compared with the diversions. (SWC 6-a1)

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AREA 7: SALINE, SODIC, AND RELATED SOILS PROBLEMS, AND QUALITY  
OF IRRIGATION WATERS AND THEIR RELATION TO PLANT GROWTH PROCESSES

Problem: Salinity is a continuing and major problem in irrigated agriculture.

In the arid West, injurious concentrations of salts in the soil have impaired the use of 25 percent of the irrigated land. Fifty percent of this area is endangered. Salinity or brackish water problems in the eastern seaboard area have increased with the rapid expansion of supplemental irrigation in this area where tidal streams and creeks are a conveniently available source. Soil salinity problems exist in many dryland farming areas in semiarid regions.

Salts move upward in the soil with water to supply evapotranspiration requirements and are left behind as the moisture passes to the atmosphere. This results in injurious accumulations in the root zone unless excess water, as rain or overirrigation, is periodically passed downward to leach the salts to the ground water or to a tile drainage system for removal in the tile effluent. These salts generally come from the irrigation water, although some soils naturally contain excessive quantities of harmful salts. The nature of the salts, soil, and climatic conditions and leaching water quality create complicated problems, many of which have not been solved. The use of salt-tolerant plants offers relief, but these plants must be identified and developed. Disposal of leached-out salts without degrading water quality for the downstream user is a critical problem.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research in the area of saline and sodic soils and quality of irrigation water for the growth and production of agricultural crops and ornamental plants. Scientists involved in this research include physicists, chemists, soil scientists, plant physiologists, agronomists, and agricultural engineers. The center for basic research in this area is the U.S. Salinity Laboratory, Riverside, California. Brackish water studies for the Atlantic Coast Flatwood Resource Area are centered at Norfolk, Virginia. Salinity problems of the Rio Grande Plain and Lower Rio Grande Valley areas are under study at Weslaco, Texas; of the Red River Valley at Mandan and Grand Forks, North Dakota; and of the Snake River Valley at Twin Falls, Idaho. In addition, four PL-480 studies are underway in Israel.

The scientific and engineering effort in this area totals 20.1 professional man-years per year, nearly two-thirds of which are at the U.S. Salinity Laboratory. Of the total professional man-years, 5.4 are devoted to mechanisms of reactions, soil properties, diagnosis, and soil-water-plant systems; 3.4 to physiological basis for plant tolerance, adaptation and response of plants; 2.0 to water composition, ground water and salt balance; 2.4 to leaching processes; 4.8 to water, soil and crop management systems for

saline and sodic soils; and 2.1 to spectral reconnaissance for diagnosis of soil and water management problems.

#### PROGRAM OF STATE EXPERIMENT STATIONS

A total of 8 scientific man-years is devoted to this area of research.

#### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

##### A. Mechanisms of Reactions, Soil Properties, Diagnosis, and Soil-Water-Plant Systems

1. Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils. The identity of the soil constituents involved in boron retention, the mechanisms of retention, and the cause of lime-induced B deficiency in plants are in question. At Riverside, California, the role of hydroxy aluminum and surface area in adsorption of B by a wide range of soils has been investigated. From studies showing (a) that precipitated  $\text{Al}(\text{OH})_3$  adsorbs relatively large amounts of B and (b) that increases in the amounts of B adsorbed by acid soils after liming are highly related to the amounts of exchangeable Al that precipitates as  $\text{Al}(\text{OH})_3$ , it has been concluded that  $\text{Al}(\text{OH})_3$  and similar hydroxy-Al materials are the major soil constituents causing B retention by soils. Moreover, it is postulated that lime-induced B deficiency in plants is caused by decreases in the B concentration in the soil solution resulting from additional adsorption by the  $\text{Al}(\text{OH})_3$  that precipitates on liming. Studies of the correlation of B adsorption with soil surface area, and  $\text{Al}(\text{OH})_3$  content as measured by Na citrate extraction, indicate that the amount of surface over which the hydroxy Al is spread is an important factor in adsorption. For a wide range of soil samples having pH values in the range 6.3-8.3, the amount of B adsorbed was highly correlated with the product of surface area and citrate-extractable Al content.

Studies have been conducted at Riverside, California, to determine whether the ion-exchange properties of soil vermiculites are similar to those of specimen vermiculites. Contrary to the usual generalization that Ca is preferred over Mg in cation-exchange reactions by soils and clay minerals, the specimen vermiculites showed a higher affinity for Mg than for Ca at soluble Mg percentages greater than 40. The soil vermiculites and montmorillonite samples, on the other hand, did not demonstrate this preference, but showed the more typical preference for Ca over Mg. Soil vermiculites have a markedly greater affinity for Na than is typical of most soil materials, with such affinity greatest at low temperatures. The latter effect suggests that, other considerations being equal, the reclamation of high-vermiculite, sodic soils might be favored in the summer. (SWC 7-gFl)

##### 2. Structure, organic matter, and microbial relations in salt-affected soils.

At Riverside, California, an expression has been derived relating hydraulic conductivity (HC) changes for a wide range of percolating Na-Ca salt solutions to predicted swelling of soil clays in these same solutions. The expression takes into consideration variations in the soil montmorillonite

content and exchangeable-sodium-percentage (ESP), and in the total salt concentration of the percolating solution. Such factors as variations in soil porosity, clay orientation, and stabilizing agents are included in a multiplicative constant which is evaluated for each soil by fitting the theoretical and experimental curves at a single point.

An estimate of the soil montmorillonite content can be incorporated into this constant as well, allowing soil HC of any other mixed-salt solution to be predicted from measurement of the relative HC to a single solution of known composition. As the dependence of relative HC on clay swelling varies somewhat with soil ESP, a nomogram has been prepared for each of three ESP ranges, permitting rapid evaluation of predicted clay swelling at any given total salt concentration and soil ESP.

In addition to the hydraulic conductivity (HC) studies on mixed Na-Ca systems, the effect of substituting Mg for Ca has been investigated for a group of soils. Relative HC to mixed Na-Mg solutions at five concentrations and three sodium-adsorption-ratio (SAR) levels averaged 6 percent lower than relative HC to corresponding mixed Na-Ca solutions, with a maximum difference between the two sets of values of 35 percent. Differences appear related to soil mineralogy. It has been concluded that the species of counter-ion is only of secondary importance in determining soil HC values in mixed-salt solutions, and that Mg behaves more like Ca than like Na in its effect on soil physical properties. (SWC 7-gF2)

3. Methods for diagnosis and study of salinity in soils and water. A combination salinity sensor and psychrometer has been developed at Riverside, California, to determine the osmotic and matric components of the total soil-water potential, and to study the interaction of the components. The combination unit makes it possible to estimate the matric component of the water potential beyond the tensiometer range. The electrodes of the salinity sensor are embedded within the walls of the ceramic bulb of the psychrometer chamber, thus giving an estimate of the osmotic potential of the water in the wall of this chamber. Since the psychrometer measures the total water potential of the same water, the difference between the two measurements should be a good estimate of the matric component of the water potential. Initial data from current tests indicate that the units perform as expected. (SWC 7-gF3)

4. The soil-water-plant system under saline conditions. The in-place soil salinity sensors developed at Riverside, California, when tested in a soil-plant system during three irrigation cycles, measured changes in the salinity of the soil solution expressed as electrical conductivity to an accuracy of  $\pm 0.5$  mmho./cm. The sensors are now being used in greenhouse and field experiments to study salt movement and accumulation in soil as influenced by evapotranspiration, water movement, chemical reactions, and diffusion. (SWC 7-gF4)

At Riverside, California, by using the field psychrometer it has been possible to instrument a soil-plant system in the greenhouse sufficiently well to collect some preliminary data on the influence of soil-water potential on transpiration rate. As the soil-water potential dropped, owing to water extraction by the plant, transpiration remained unimpeded until the soil-water potential reached -5 bars. At this time the plant-water potential dropped to about -10 bars during the day, but returned to the same water potential as the soil during the night when transpiration was low. When the soil-water potential dropped to -15 bars, the plant-water potential decreased as low as -22 bars during the day and remained below -18 bars during the night. By this time, transpiration was reduced to less than 10% of its initial value. This is approximately the amount generally attributed to cuticular transpiration, indicating that the stomates were continually closed. Thus, for the conditions under which this experiment was run, the traditional 15-bar percentage was a realistic lower limit for available water. However, the fact that transpiration rate was significantly reduced long before this value was reached indicates that plant growth was severely reduced because of stomatal closure during the day. With aerial conditions imposing a high evaporative demand, the water potential of the plant probably would fail to return to that of the soil during the night at a higher water content than the 15-bar percentage. Experiments are underway to test this hypothesis. (SWC 7-gF6)

## B. Physiological Basis for Plant Tolerance, Adaptation and Response of Plants

1. Tolerance of plants to salinity--arid areas. At Riverside, California, field-plot harvests of the ratoon crop of H50-7209 variety of sugarcane qualitatively confirm the observation of decreasing salt tolerance with increasing age of stand. The N Co 293 and 310 varieties suffered approximately a 40% decrease in salt tolerance of the ratoon as compared with the seed crop, but the Hawaiian 50-7209 was only about 20% less tolerant in the second year than in the seed-crop year. The Hawaiian variety, although more salt-sensitive than the N Co varieties, appeared to be less affected by smog and more resistant to low night temperatures and produced much higher yields in the nonsaline field plots than the two N Co varieties. Since perennial species generally increase somewhat in salt tolerance with increasing age of stand, the decreasing tolerance of sugarcane is of unusual interest. Facilities will shortly be available for studying the interactions of salinity and environmental factors, and the underlying causes for the increasing salt sensitivity of sugarcane with age will be further investigated. (SWC 7-gF5)

Although salt-tolerance experiments have often involved an excess of one or more nutrients, little is known regarding the interaction of nutrient deficiencies and salinity. In studies of the interactive effects of salinity and N and P levels on growth of sweet corn at Riverside, California, ear yields were about twice as great in the spring as in the fall experiment, and salinity effects were also greater. Low N depressed yields at all salinities and the yield curves for different N levels tended to be parallel, indicating no important interaction of N levels and salinity on yield. But high P exaggerated the inhibitory effect of salinity, causing the yield curve to fall

off more sharply with increasing salinity than the yield curves for low and medium P. Phosphorus deficiency did not occur at any P level. (SWC 7-gF9)

2. Tolerance of plants to salinity--humid area. Continuing studies at Norfolk, Virginia, substantiate the fact that beans are more sensitive to salinity in early growth stages than at more mature stages. By using nutrient solutions, substrates were salinized (12 mmhos./cm.) and desalinized (base nutrient solution) over three growth stages during which plants were salinized for one-third, two-thirds, or all of the time. Results indicated that plants salinized during the first growth stage were not only more sensitive than those salinized during the second or third growth stage, but showed some carry-over effects when desalinized during the second growth stage. This was evidenced by a lower evapotranspiration rate than that of the control.

Field and greenhouse investigations at Norfolk, Virginia, show that crops vary in sensitivity to foliar damage from synthetic sea water spray. In the greenhouse, a 15-minute exposure to 1/2 sea strength spray reduced yields of beans and peppers, but corn yields were reduced only with full sea strength spray. In the field, 1/8, 1/4, 1/2, and full strength sea water was sprayed on four crops for two 3-1/2-minute durations, two weeks apart. Foliar absorbed and adsorbed chlorides increased with amount applied, but the amount absorbed did not correlate closely with the amount adsorbed on the leaves. Eggplant yields were reduced significantly by 1/4 sea strength spray. No salt reached the soil in these studies. Farmers seldom use irrigation waters as saline as 1/4 sea strength. Yet, since plant injury has been obtained where more dilute saline solutions have been used and allowed to enter the soil, it is suggested that the major hazard from field applications of these waters results primarily from accumulated salinity in the soil rather than from foliar injury. (SWC 7-a1)

3. Physiological basis for plant tolerance to saline soils and water. Research at Riverside, California, has shown that the suppressive effect of salinity on water uptake by roots is only partially reversed by decreasing the salt content of the root medium and appears to involve irreversible structural and functional changes in the root cells. One of the first detectable responses of root cells to salinity is a release of polymers including polysaccharide, protein, and lipid. These polymers are of cell-wall and cell-membrane origin. Their release occurs during brief exposure to salt (40 to 100 meq./l.) at 0°C., conditions that would largely limit contact with salt to the cell surface. They are not released during exposure to solutions of un-ionized solute at isomotic concentration, so the effect is ionic rather than osmotic. It appears that the salt selectively extracts a fraction of the cell wall membrane complex which is essential for solute accumulation and for maintaining the semipermeable character of the cell membrane. This salt effect increases with the salt concentration of the solution and with the length of exposure. It is also influenced by the nature and combination of ions present. In time, the injury progresses from the cell surface to the vacuolar membrane; the membrane becomes leaky, and the

cells lose vacuolar solutes, water, and presumably, turgor, even while immersed in water. Eventually, intercellular connections visibly break down.

At Riverside, California, a study of the effect of salt concentration on the properties of enzymes has been undertaken with the hope that information concerning the mechanism of salt damage to plants will be obtained. Malic dehydrogenase, an enzyme important in the energy metabolism of the cell, was isolated from pea seed extracts. Its activity was strongly affected by ionic strength, and the degree of effect was a function of salt concentration, substrate concentration, and pH. Further study revealed that malic dehydrogenase is subject to two different effects of NaCl. At concentrations of 0.02 M or higher, NaCl inhibits the reaction in a manner suggesting competitive inhibition. At concentrations below 0.02 M, NaCl stimulates the reaction by a mechanism that can be explained in terms of blocking substrate inhibition of the enzyme. As these observations also are obtained with other monovalent cations, this stimulation or inhibition of the enzyme is a nonspecific cationic effect. (SWC 7-gF7)

4. Effects on plants of specific ions associated with salinity or exchangeable sodium. The dominant effect of salinity on woody plants consists of the accumulation of toxic concentrations of ions such as Na and Cl in the leaves and stems. To select or develop superior rootstocks, information is needed on the mechanism by which absorption and translocation of toxic ions is controlled.

At Riverside, California, experimental work was conducted with beans and cotton, as bean plants have an effective mechanism for preventing translocation of Na from the root to the shoot whereas cotton does not, and both can be cultured more readily than woody plants. Metabolic inhibitors had no consistent effect on the total amount of Na absorbed by bean plants, but decreased accumulation in the roots and increased translocation to the shoot. In cotton, metabolic inhibitors generally reduced absorption by the plant, accumulation in the root, and translocation to the shoot. Translocation of Na was related to transpiration in cotton, whereas, in beans, such a relation existed only after suppressing root accumulation with an inhibitor. The Na content of both bean and cotton shoots was greatly increased by killing or removing the secondary roots. Under these conditions the metabolic inhibitor, dinitrophenol, reduced the amount of Na retained in bean stems and petioles, and thus increased the amount carried into the blades. It has been concluded that in beans Na is withdrawn from the xylem stream by living cells adjacent to the vascular tissue and that this withdrawal mechanism is dependent upon metabolic activity. The Na-withdrawal mechanism is much less pronounced in cotton than in beans. (SWC 7-gF8)

5. PL-480 studies in Israel. In a study of the effect of salinity on plant metabolism, the incorporation of leucine into the protein of pea roots was hindered by the salts. This decreased linearly with increasing concentrations of chloride salinity but rather abruptly with sulfate salinity. (A10-SWC-7)

In a study of the physiological adaptation of plants in a saline environment to moisture and osmotic stresses, three distinct phases of Cl-uptake were found in salt-loaded tissues, but only two in unloaded tissues. Free-space volumes appeared to be affected by internal chloride content. Various parts of salt-treated pea and bean plants showed increased respiration although total growth rates were retarded. (A10-SWC-30)

In a study of the mechanism of water and solute flow in plant roots, differences in electrical potential were indicated between the vacuole and intercellular space and also between the vacuole and the surrounding cytoplasm. Previous investigations have found only the former. Since ion pumps have been postulated at the tonoplast as well as the plasmalemma, these findings, if verified, would be consistent with the existence of pumps at both membranes. (A10-SWC-31)

#### C. Water Composition, Ground Water and Salt Balance

The assessment of irrigation water quality is basic for proper planning of irrigation projects and is currently of major concern in establishing water quality criteria. Except for waters prohibitively high in boron, sodium, or some other component, the suitability of a water for irrigation depends on the conditions of use. These include (1) the permeability and drainage of the soil, (2) climatic conditions, (3) irrigation management practices, and (4) the salt tolerance of the crop or crops. A system for taking into account all the pertinent use factors in assessing irrigation water quality has been developed at Riverside, California. The method is based on the calculation of the potential leaching fraction as a function of evapotranspiration, infiltration rate, and irrigation cycle and duration for the case of nonlimiting drainage. Where drainage is limiting, the leaching fraction is calculated as a function of drainage and evapotranspiration rates. From the calculated leaching fraction and the known upper limits of crop tolerances to total salts and specific ions, the maximum permissible limits for the irrigation water are computed.

A water with less than the maximum permissible limits is suitable for the specific use conditions. If the water contains more than the maximum permissible limits, the water is unsuitable unless use conditions can be modified to increase the maximum permissible limits. (SWC 7-gF10)

#### D. Leaching Processes

In an effort to better delineate the processes contributing to the broadening of salt fronts moving through soils, studies have been initiated at Riverside, California, relating the elution of salts from soil columns to various properties of the flow system. Elution patterns have been compared for both solid-phase and dissolved salts, as a function of solution flow rate and of column length. At water contents near saturation, the rate of dissolution of solid-phase salt in the flow stream is commonly of greater importance than the dispersion of the salt front in the soil in determining

the rate of elution of solid-phase salt from the soil. Though this effect should become less pronounced at the low rates associated with water movement through unsaturated soils, even then the assumption of equilibrium between solid-phase and dissolved salt may be inaccurate for many situations. The rate of dissolution of solid-phase salt has been shown to be dependent upon the flow rate through the salinized zone, the degree of contact between the salt and soil, the size of the salt crystals, and the type of salt present. (SWC 7-gFl1)

Six years of record at Norfolk, Virginia, indicate that brackish water can be used for supplemental irrigation without any appreciable buildup of soil salinity. Studies were conducted on three soil types. Winter rainfall was usually adequate to leach any accumulated salts below the root zone. Leaching was more rapid on coarse-textured than on fine-textured soil. Under certain conditions of low winter rainfall and high evapotranspirative demand in spring or early summer, some salt moved back up to the surface, but the amount was not detrimental to crop growth. Under extreme conditions, however, this could be a hazard. There was no apparent effect of salinization on final soil pH. Exchangeable Na increased with increasing salinization, but the effects on exchangeable K, Mg and Ca were insignificant. (SWC 7-a1)

Irrigation practices put into effect while growing a cotton crop has resulted in the removal of over 16 tons of salt per acre at the Drainage Research Farm at Brawley, California. This quantity of salt removed in one year is 30 percent of the amount initially present in the 0- to 6-foot soil profile. The irrigation practice of using the drain tile systems to help saturate the soil profile and dissolve more soil salts has worked well at this location where good horizontal but poor vertical water movement characterizes the soil profile. (SWC 7-gl)

#### E. Water, Soil and Crop Management Systems for Saline and Sodic Soils

North Dakota and adjacent states have several million acres of sodium-affected soils. These and associated rangeland soils are unproductive and, because of their low water intake, contribute to flood hazard. Studies on small plots near Mandan, North Dakota, indicate that mixing the top 16 inches with soil amendments of gypsum and manure reduce adsorbed sodium, increase water intake several-fold and increase production of western wheatgrass over twofold. These results suggest that the productivity and hydrology of affected areas can be improved, and research has been initiated on larger areas to test the possibility. (SWC 7-d1)

Large tracts of land in southwestern Idaho are being considered for development under irrigation. Much of this land had previously been classified as poorly suited for irrigation because of extensive areas of slick spot (saline-sodic) soils. Most of these soils are on level to gently sloping lands ideally suited for irrigation. The distribution of the problem soils is such that treatment of individual spots is impractical, and

any treatment imposed must be applied to the entire field. Previous experience with deep plowing as a soil improvement or reclamation practice has been very successful in southeastern Oregon and southwestern Idaho. This treatment was used in 1966 as part of a 3-year study of new land under consideration for development. Typical large first-year increases in water and root penetration were obtained, along with increased yields. Greenhouse lysimeter studies were also initiated in 1966, using soil from field sites as a more economical approach toward solution of the problem. Early results indicate that this technique may adequately predict the success of field deep plowing as a soil improvement or reclamation practice. (SWC 7-fl)

Preliminary study of Carson clay soils in western Nevada indicates that their inherent high salinity is related to the soil-forming processes, which have resulted in clay contents often exceeding 70 percent and soil permeabilities of less than 0.01 foot per day. Some of these soils have responded to deep plowing, applications of gypsum, and careful irrigation water management with good quality water. (SWC 7-gl)

In northern Nevada, a study to determine the feasibility of replacing greasewood with vegetation of more economic value has shown that the area consists of small one-foot-high dunes occupied by the greasewood and surrounded by barren interdune areas. The soil in the middle of the dunes is relatively low in salts, but has a high pH, and contains firmly cemented layers at relatively shallow depths. The cemented layers tend to occur in the presence of high pH, low salts, and high exchangeable sodium. The barren interdunal areas contain highly dispersed silty soils with a surface vesicular crust about 1/2 inch thick. These latter soils are high in exchangeable sodium, quite impermeable, and have occasional salts visible on the surface. Apparently, the greasewood plants play a role in the formation of silica-cemented zones in the soil profile under certain conditions, since the cementation is more strongly pronounced and occurs at a shallower depth under plants than in the barren areas. Greasewood leaves contain large amounts of sodium oxalate. When the leaves decompose, the released sodium raises the soil pH and solubilizes silica which acts as a cementing agent. The presence of silica-cemented layers will have to be considered in developing practices for establishing and maintaining seedlings adapted to these soils. (SWC 7-gl)

#### F. Spectral Reconnaissance for Diagnosis of Soil and Water Management Problems.

Important soil characteristics and soil conditions were related to thermal infrared scanner imagery at Weslaco, Texas. Equivalent blackbody temperatures determined from thermal imagery were related to soil particle size and to variations in texture with depth in the soil profile. Soil moisture content was determined qualitatively from diurnally flown imagery. Diurnal variation in surface temperature for dry soils in two fields averaged about 48°C., but was only 41°C. in a field of higher soil moisture content.

In a study of plant geometry using airborne thermal infrared imagery at Weslaco, Texas, it has been shown that a highly significant correlation exists between the equivalent blackbody temperature of vegetated sites and the percent of crop cover. Soil is generally at a higher temperature than plant leaves growing on the area. The variation in temperature with percent cover is due to soil exposure.

At 1359 hours on June 1, 1966, when incident direct plus diffuse radiation was 1.41 ly./min., the temperature spread among sites was 39°C., ranging from 31°C. for an irrigation reservoir to 70°C. for lister beds smoothed and shaped for planting. Temperature resolution was about 0.5°C. for this wide temperature range in targets. At 0606 on June 1, the range in target temperatures was 11°C. with temperature resolution of 0.2°C. The results illustrate the application of thermal imaging to agricultural problems. (SWC 7-18(e2))

A study of the factors affecting reflectance and emittance of energy by cotton grown on saline and nonsaline soils at Weslaco, Texas, showed that the reflectance of leaves was affected by their age, moisture and salt content. Single leaves from cotton grown on saline soils reflected more of the incident radiation than leaves from cotton grown on nonsaline soils. A decrease in the relative turgidity or an increase in the chloride content of the leaf blade increased reflectance.

Reflectance from a crop canopy as recorded on photographic film was affected also by soil salinity, leaf moisture and chloride content, and by the percentage ground cover. As these factors also affect cotton yields, regression equations were calculated expressing cotton lint yields as a function of film density. Coefficients of determination ranged in value from 51 to 75 percent. (SWC 7-e1)

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AREA 8: WATER AND WIND EROSION CONTROL PRINCIPLES,  
PRACTICES, SYSTEMS AND PREDICTION METHODS

Problem: Soil erosion is a widespread hazard, limiting land capability on 738,000,000 acres in the United States. Erosion by water or wind, or both, continues to be a problem in all areas having cropping systems that require plowing, tilling, and planting. It is also a problem of increasing importance on construction sites.

Erosion is the major source of stream pollution. Uncontrolled erosion in the United States produces nearly 4 billion tons of sediment each year. One fourth of this reaches the ocean. An estimated 380 million cubic yards of sediment are dredged each year from the Nation's harbors and waterways at a cost of \$125,000,000.

Sandblasting has caused serious damage to young plants in the sandy vegetable-producing areas of the humid region as well as in drier areas. Careless application of irrigation water has resulted in serious erosion.

Continued development of new erosion control practices and modification of existing ones are necessary to meet the needs of an ever-improving farm technology and the expanding use of multi-row farm equipment.

The wide variations among different soils, climates, crops, and management systems create highly complex relationships that make it imperative to determine basic principles governing the movement and loss of soil and water. Improved control measures and prediction equations developed from these principles will provide a scientific basis for application of control practices, identification of potential sediment sources, preparation of land use recommendations and selection of critical areas for retirement to permanent vegetation.

USDA AND COOPERATIVE PROGRAMS

The Division conducts both basic and applied research and development in the area of water and wind erosion utilizing soil physicists, soil scientists, analytical statisticians, and agricultural engineers at various physiographic areas and field stations throughout the United States. The scientific and engineering effort in this area totals 22.6 professional man-years per year with 8.9 devoted to basic principles and mechanics of water and wind erosion; 5.5 to interrelations of climate, soil, topography, cover, and management; 0.8 to predicting soil and water loss; 5.5 to practices, structures and systems for modification of soil movement by wind and water; 0.9 to loss of nitrogen in runoff and erosion; and 1.0 to equipment and techniques for study of runoff and erosion.

## PROGRAM OF STATE EXPERIMENT STATIONS

A total of 12 scientific man-years is devoted to this area of research.

### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

#### A. Basic Principles and Mechanics of Water and Wind Erosion

1. Mechanics of water erosion. Detailed analyses of photographed raindrops taken during 356 minutes of rainfall at Urbana, Illinois, showed that the relation of average drop size distribution to rainfall intensity was similar to the classic results of Laws and Parsons (AGU Trans., 1943). For individual storms, however, considerable deviation occurred for this relationship. A rotating vectopluiometer was used to determine the dominant angle of impact for 33 storms. The average impact angle deviated less than  $30^\circ$  from vertical for only 6 storms, was less than  $45^\circ$  for 18 of the storms, and was less than  $60^\circ$  for 24 of the 33 storms. Nine storms had dominant impact angles of  $60^\circ$  or more from vertical. Knowledge of raindrop size distributions and impact characteristics is necessary to determine rainfall erosivity. (SWC 8-cl)

Raindrop studies at Holly Springs, Mississippi, showed the median drop size in 70 samples of natural rainstorms was proportional to rainfall intensity. The median drop size ranged from 1.5 mm. at 0.04 in./hr. to about 3 mm. at 3 in./hr., the highest intensity studied. The minimum drop size of about 0.4 mm. was measured with all intensities. The maximum drop size tended to increase with rainfall intensity. (SWC 8-bl)

At Manhattan, Kansas, wind-driven rain was found to be an important factor in clod destruction. Up to 66 percent more soil was detached from clods exposed in rain driven by a 30-mile-per-hour wind than from clods exposed to rain of equal intensity and duration without wind. Clod size, soil bulk density, duration of exposure to rain, rainfall intensity, and wind velocity were the variables studied to learn more about factors influencing clod dissipation and to supplement other research which is attempting to develop methods of producing greater soil cloddiness for wind and water erosion control. Persistence of the clods to the beating and wetting action of rainfall was also strongly related to size of clog and to intensity and duration of rainfall. Clod bulk density was of minor importance. For a specific clod size and wind velocity, short-duration, high-intensity rains were more destructive than long-duration, low-intensity rains. Small clods were more readily destroyed by raindrop impact than large clods. Multiple curvilinear regressions showed that the five variables studied accounted for 84 percent of the variation in soil detachment from the clods. (SWC 8-10(e2) Rev.)

Continuing studies of raindrop splash geometry at Morris, Minnesota, showed that both splash height and crater width increased as drop fall velocity increased. The greatest change occurred at the lower velocities. For drop diameters of 2.9 to 5.6 mm. and surface water depths equal to  $1/4$  the drop diameters, the splash sheet angle was nearly vertical for all but very low velocities. However, the projected direction of splash droplets varied from about  $60^\circ$  from vertical at a fall velocity near 3.3 meters per second to vertical at terminal velocities for these conditions. Raindrop splash is a dominant factor in initiating soil erosion by water. (SWC 8-cl)

In studies of overland flow at Lafayette, Indiana, velocities varied from 0.2 to 1.6 feet per second for slopes of 4 to 10 percent, lengths equivalent to 40 to 100 feet at 1- $1/2$  inches per hour of runoff, and mulch rates up to 1 ton per acre. Most velocities were much less than 1 foot per second. For comparable conditions, runoff velocities were greater with the smaller soil particles than for the larger owing to the development of deeper rills with the smaller sizes. (SWC 8-cl)

Analysis of time-lapse movies obtained during all runs in the mechanics of erosion studies at Lafayette, Indiana, showed that the geometry of diamond-shaped erosion patterns that developed during overland flow was related to topographic and soil conditions and to the resulting erosion. Preliminary results indicated that the length of the erosion pattern varied with slope steepness, slope length, particle size, and erosion rate, but that the width of the pattern was not significantly affected by these variables. Relationships between erosion patterns and the resulting erosion may make possible the estimation of erosive characteristics of agricultural fields based on the geometric patterns that develop on these fields. (SWC 8-cl)

Studies at Lafayette, Indiana, also showed the effectiveness of small rates of surface mulch depended on slope length, slope steepness, soil particle size, and type of erosion pattern. Mulches became less effective as slope steepness and slope length increased. Mulch rates of  $1/2$  or 1 ton per acre decreased erosion of both the 33-micron and 121-micron particles. Rates of  $1/8$  and  $1/4$  ton per acre also decreased erosion of the 121-micron particles, but often increased erosion of the 33-micron particles, apparently because of turbulence and increased flow velocity around the sparsely scattered straws. Surface mulch rates of considerably less than 1 ton per acre are often easier to obtain under field conditions and are less likely to seriously depress soil temperatures than the several tons per acre often recommended for erosion control. (SWC 8-cl)

Wheat-sized plant stems in rows or random orientations and separated by several stem diameters increased erosion from a plane soil surface. This effect was relatively greater for 4 percent than for 7 percent slope. Stems in up and down slope caused several times more erosion than no stems at 7 percent slope and nearly 30 times more erosion at 4 percent slope. This phenomenon, which also occurred for sparse mulch straws, was attributed to increased localized flow velocities and turbulence near the stems. The

influence of this "pier" effect of crop stems and residues has not been previously linked to agricultural conditions. (SWC 8-cl)

The land-slope profiles developed by successive periods of soil erosion were studied in Minnesota for several initial shapes using two erosion equations. For a slope averaging 5 percent for 400 feet, maximum erosion rates varied from approximately 100 units near the base of the convex slope, to 40 units near the base of the uniform slope, to 30 units about 260 feet down the complex slope, and to less than 15 units near the center of the concave slope. The depth of erosion varied similarly. These results indicate that shaping the final profile around buildings and for highway embankments to a concave slope may reduce erosion and sediment losses greatly. They also show where terraces or other erosion control measures will be of greatest benefit on existing field slopes. (SWC 8-cl)

2. Mechanics of wind erosion. At Manhattan, Kansas, a wind tunnel study to determine the effect of barrier porosity on windspeed reduction provided some useful information on the momentum transfer processes occurring when a barrier is placed in the path of the wind. The study, carried out as a preliminary to a more comprehensive field study of the influence of summer winds and barriers on the energy budget, showed that within the zone of influence of the barrier and below heights of 1.5 to 2.0 times the height of barrier, windspeed reductions are associated with momentum transfer processes. There was a transfer of momentum without loss of total energy with increased windspeed to zones above 1.5 to 2.0 times the height of barrier. The data also showed that the lower the porosity of the barrier, the greater the windspeed reductions close to the leeward side and the smaller the reductions at greater distances leeward. Slat-fence barriers with porosities of 60, 40, 20, and 0 percent were studied. The 40-percent porosity barrier caused the greatest leeward windspeed reduction over the 0- to 30-H interval. Overall average percentage windspeed reductions for the barriers did not change substantially with variation in open tunnel windspeed; however, there were some barrier porosity-windspeed interactions which caused percentage windspeed reductions to vary at particular leeward locations depending on the level of open wind. (SWC 8-el)

3. Freeze thaw effects on runoff and erosion. Large differences in land slope direction occur in the Palouse region of the Pacific Northwest. The effects of slope direction on rate of snowmelt and runoff in the spring are visually apparent, but the thermal regime of the soils on these slopes and its effect on infiltration and runoff is not known. Midafternoon soil temperatures at the 5-cm. depth on south- and north-facing slopes slowly approached equality from October to December due to lower mean elevation of the sun and cloudiness. Differences between air and soil temperatures were small on the south-facing slopes in October, but large on the north-facing slopes. These preliminary data indicate that during the day sensible heat from the air is being absorbed by the soil on north-facing slopes. Similar results are expected as radiation increases in the spring. These preliminary data indicate that the thermal regime of south-facing slopes is strongly influenced

by solar radiation but the thermal regime of north-facing slopes is influenced more by air temperature. (SWC 8-f1)

4. Soil crusting and erodibility. In laboratory investigations of soil properties that affect its erodibility at Ames, Iowa, large soil aggregates beneath the surface impeded infiltration after raindrop action had closed the pores between aggregates at the surface. The pores between large aggregates allowed rapid entry of water into the soil for a considerable time period. However, when disintegration by raindrop action finally filled the pores at the surface, conductance of water through the consolidated surface layers was slower on beds of soil aggregates with pores greater than a few tenths of a millimeter than on beds having only finer aggregates. The degree of discontinuity between the disintegrated surface layer and the aggregated soil beneath it appeared to become an important factor in reducing infiltration rates. (SWC 8-c2)

At Lafayette, Indiana, modulus of rupture measurements were made on samples of 60 Corn Belt soils to characterize differences in surface crusting and determine specific soil properties to which the variation in surface sealing resulting from rainfall is related. Surface crusting differed greatly between soils having different textures, organic-matter contents and structure. Rainfall impact did not appreciably increase modulus of rupture measurements but did significantly reduce water permeability. Ratios of hydraulic conductivities of rain-exposed samples to no-rain samples varied from 0.14 to 0.94. (SWC 8-c2)

Studies at Orono, Maine, revealed a direct relationship between runoff, soil loss, and crust formation. For six soil types studied, soil loss and runoff increased rapidly for the first ten minutes of rainfall. Soil loss then decreased gradually for the Marshall, Dunkirk, Caribou and Nicholville soils, but continued at a uniform rate for the Hartland and Winooski soils. Differences were directly correlated with the formation of surface crusts. For the six soils evaluated, there was a positive correlation between the modulus of rupture of the crust and the clay content of the soil. (SWC 8-a1)

Studies of aggregate stability showed a significant size-stability interaction between Marshall silty clay loam subsoil and topsoil. In the 0.5- to 2.0-mm. size range, aggregates from the A horizon were more resistant to breakdown by waterdrops than those from the B horizon; in the 8- to 30-mm. size range, aggregates from the B horizon were more stable than those from the A horizon. This is significant because it shows the potential for plow-plant methods to increase water intake on Marshall soils that have been seriously eroded, or "scalped" during terrace construction.

At Lafayette, Indiana, a soil-erodibility equation was derived which may meet the immediate need for erodibility determinations on silt loam, silty clay loam, silty clay, clay loam and loam soils. The relationships expressed by the equation accounted for 96 percent of the total soil-loss variance on 100 scattered field plots tested under identical rainstorms and surface conditions.

Not all soils falling within a given type and texture classification were equally erodible. Neither was the erodibility of a given soil the same at different antecedent moisture conditions. The derived erodibility equation makes possible the delineation of conditions under which a given soil classification should, for practical purposes, be subdivided and assigned more than one erodibility value, and it is an effective tool for calculating erodibility values that reflect representative conditions. (SWC 8-c2)

5. Erosion tolerance and renewal. Continued operation of 18 cooperative dust trapping stations from headquarters at Manhattan, Kansas, has provided additional information on amounts of dust influx, relation of influx to climatic and site variables, and qualitative characteristics of the dust which are useful in erosion tolerance and soil renewal considerations. Mean monthly dust deposition during 1966 ranged from 188 pounds per acre at Tribune, Kansas to 12 pounds per acre at Coshocton, Ohio. Longtime monthly averages are now 410 pounds at Tribune and 15 pounds at Coshocton. The most useful independent variables for relating dust deposition rate to climate and site are average wind velocity measured at Dodge City or Goodland, Kansas, or in some cases, wind velocity near a sampling station, raised to the third or fourth power; rainfall or rainy days near the station; and seasonal indexes, which reflect ground cover. Regression analyses using these variables accounted for from 40 to greater than 90 percent of the monthly variation at 9 of the stations. Despite positive correlations with wind velocity measured near the old dust bowl, qualitative analyses of the dust showed higher pH and phytolith counts westward and higher clay and organic matter percentages eastward, indicating influences of local environment. Positive identification of ubiquitous, amorphous, nonorganic particles in dust, such as grass phytoliths of mainly silica and water composition, should aid in determining sources of modern dust. Spodograms and ash of prominent grass species were used as a basis for classification of the phytoliths into 26 types and 4 classes, 3 of which are keyed to grass families of regional occurrence. (SWC 8-e1)

At Manhattan, Kansas, additional steps have been taken toward solving a general soil erosion tolerance equation. Mathematical foundation was laid for selecting erosion and renewal functions that can be manipulated to provide realistic solutions to erosion and renewal problems. One case uses functions for the erosion rate and for the renewal rate to show what occurs when starting with initial cultivation of deep soil and continuing until a conservation balance is achieved. A second case uses a function to show net change of favorable depth over time as erosion control and renewal practices are gradually intensified. A third case uses a function to illustrate erosion or dilution of an initially high percentage clay topsoil over time by deposition of highly silty sediment from the atmosphere. This sample showed that with time in decades, surface soil 50 percent clay, atmospheric dust 20 percent clay, and annual dust deposition rate 500 pounds per acre, initial change of clay would be about 0.1 percent per decade. (SWC 8-10(e2) Rev.)

## B. Interrelations of Climate, Soil, Topography, Cover, and Management

1. Water runoff and erosion. Studies at Presque Isle, Maine, on a stony Caribou soil showed that rock removal from land in continuous potatoes resulted in a decrease of 38 percent in soil water storage. Where rocks were crushed and returned, a decrease of only 3 percent was observed. Runoff and soil loss for 1966 confirmed previous trends for rock removal and cropping. Since rock removal is necessary for potato production in many areas, development of a practical procedure for crushing and returning the rock material to the soil would be most beneficial from the standpoint of decreasing soil loss and conserving soil water. (SWC 8-a1)

Runoff and soil losses on Tifton loamy sand of 3 percent slope at Tifton, Georgia, for the 11-year period, 1956-66, from cropping systems of fallow soil; corn continuously; a 3-year rotation of oats, rye green manure and corn, and peanuts; and a 4-year rotation of bahiagrass and clover 2 years, corn, and peanuts averaged 11.84, 1.32, 1.66 and 1.62 inches runoff and 5.12, 0.79, 0.89 and 0.60 tons per acre soil loss, respectively. There was a general decline in organic matter content of the soil with all these cropping systems during the 11 years. (SWC 8-b1)

Six years of measurements to characterize runoff and erosion on Barnes silty clay loam in the northern Corn Belt States showed that 32 percent of the water loss and 72 percent of the soil loss from corn plots occurred during the first 60 days after corn planting. In the oat years of a corn-oats-meadow system, 85 percent of the water loss and essentially all of the soil loss occurred within 60 days after oat seeding. Erosion-control practices designed for this physiographic area need to exert their greatest benefit during this relatively brief time period. (SWC 8-c2)

Tests under simulated rainstorms at Lafayette, Indiana, showed the erosion-reducing effectiveness of narrow row spacing for corn and soybeans was closely related to the portion of the soil surface covered by the crop canopy. Percent ground cover 8 weeks after planting was little influenced by corn-row spacing, and 20-inch rows lost about 15 percent less soil than 40-inch rows. At harvest time, the 20-inch rows provided 30 percent more cover and lost 60 percent less soil. Four weeks after soybean planting, soybeans drilled in 7-inch rows covered 70 percent of the soil surface in contrast to from 20 to 40 percent with 20-inch row spacing, and lost 25 percent less soil. At 8 weeks, canopy cover was 35 percent greater and soil loss 30 percent less with the 7-inch spacing. During the latter half of the growing season, both runoff and soil loss were greater from corn than from beans with comparable row spacing. (SWC 8-c2)

At Morris, Minnesota, in studies of the influence of furrows of varying ridge-slope length and varying ridge angles, the flow velocity of surface runoff and soil loss per unit width of furrow increased as ridge-slope length became greater. Increasing the ridge angle did not increase flow velocity but did increase soil loss per unit width of furrow, indicating that more soil

particles were moved into the furrows by raindrop splash. Knowledge of the effects of differences in oriented microtopography can play an important part in design of improved tillage techniques for erosion control. (SWC 8-c2)

Studies at Pendleton, Oregon, indicated that leaving wheat stubble standing over winter resulted in 1 to 2 inches more water stored in the 4-foot profile as compared to stubble plowed in the fall of 1965. Similar results were observed in farm fields in the Pullman-Moscow-Colfax area of Washington and Idaho where side-by-side comparisons showed that about 2 inches more water were stored in the soil where wheat stubble had been chiseled in the fall as compared to moldboard-plowed wheat stubble. Runoff reduction is an important factor in reduction of soil erosion. (SWC 8-f1)

2. Wind erosion. Twenty-four years of study at Bushland, Texas, to evaluate the longtime effects of stubble mulch farming on wheat yields, soil tilth, moisture conservation, wind erodibility, weed and insect control, and soil nitrogen have shown stubble-mulch farming, particularly the delayed fallow system, maintains higher wheat yields than clean tillage and provides plenty of residue for effective wind erosion control. Tillage treatments have been: (1) one-way plow, (2) stubble mulch (subtillage), (3) field cultivator (Hoeme chisel), and (4) delayed stubble-mulch (delayed subtillage). Delayed stubble-mulch was used on wheat-fallow-wheat cropping systems. All other tillage treatments were used on both wheat-fallow-wheat and continuous wheat cropping systems. Measurements of soil physical factors at the end of 24 years have shown continuous wheat plots to have higher organic matter contents than rotations, and delayed subtillage plots to have more water-stable aggregates, more soil organic matter, and a larger percentage of dry soil aggregates greater than 0.84 mm. in diameter (nonerodible) than other treatments. (SWC 8-e1)

At Manhattan, Kansas, a prototype tillage machine is being developed that will permit intermittent or continuous packing of the soil immediately ahead of chisel tillage elements. The soil packing is for the purpose of increasing the cloddiness potential of field soils, thereby reducing soil erodibility. A satisfactory design for the reciprocating impactors has been accomplished. It includes an eccentric as a cam and the impactor shaft as a follower. Length of stroke is 4 inches and a compression spring maintains positive contact between cam and follower and furnishes the force for the return stroke. Power will be transmitted to the camshaft from the tractor power take-off through a right-angle drive unit and appropriate sprockets and roller chains. (SWC 8-e1)

### C. Predicting Soil and Water Loss

1. Water runoff and erosion. Studies at the Runoff and Soil-Loss Data Center in Indiana showed that the sediment content of runoff from cultivated or denuded upland soil can be closely predicted from 18 measurable physical properties of the soil, topography, surface condition and factor interactions. These included texture, soil structure, organic-matter content, aggregation,

pH, underlying material, slope shape, slope steepness and length, effects of recent sod crops, antecedent moisture, and average depth of runoff. In 300 field tests encompassing a broad spectrum of soil types and textures, soil content of the runoff varied from 1.5 to 17.3 percent, by weight. Differences in sand, silt, and clay content accounted for only 20 percent of the variance; but all factors combined in a predictive equation, accounted for 96 percent.

The potential accuracy for a prediction of surface runoff from plot source upland areas was significantly improved by the identification and evaluation of 16 soil properties, profile characteristics and surface conditions that influence the capacity of a coverless soil surface to infiltrate intense rains. Primary and interacting effects of the 16 variables accounted for 90 percent of the total runoff variance in data from 100 test sites. This information will be combined with cropped-plot data and basic physical concepts to derive a general runoff-prediction equation for cropland. (SWC 8-c3)

At Morris and St. Paul, Minnesota, a computer technique was developed for calculating the topographic factor (LS) of the soil loss prediction equation based on the assumption that water and soil movement is along parallel rows in a field with irregular topography. The technique gave results that agree closely with field studies. (SWC 8-c3)

Runoff and soil loss studies on Tifton loamy sand of 3 percent land slope at Tifton, Georgia, during the period 1956-66 have provided cropping factor values for use in the soil-loss prediction equation as follows: peanuts continuously = 0.54; corn continuously = 0.34; 3-year rotation of oats, rye green manure and corn, peanuts = 0.49; 4-year rotation of bahiagrass and crimson clover 2 years, corn, peanuts = 0.30; and bermudagrass and crimson clover meadow = 0.13. These values suggest there is little erosion control benefit on this soil from the rotation sequences studied, as compared with corn continuously where the corn residue is left on the land. The erosion hazard is higher, however, from peanuts and other crops where the residue is removed from the soil surface. (SWC 8-b1)

2. Wind erosion. At Manhattan, Kansas, analyses of wind data to assess the capacity of a wind to cause erosion and to compute prevailing wind erosion direction and preponderance of wind erosion forces in the prevailing direction were completed for 212 locations in the United States. A manuscript to be published as an Agriculture Handbook was prepared giving an abbreviated description of analyses and a discussion of orientation of barriers, stripcrop, and other erosion control practices. Equivalent field width based on preponderance of wind erosion forces in the prevailing direction is discussed. The data are also used in combination with the wind erosion prediction equation in examples of field applications for determining potential wind erodibility of farm fields and determining barrier spacing. (SWC 8-e1)

At Manhattan, Kansas, a monthly wind erosion climatic factor to evaluate the influence of wind velocity and surface soil moisture on amount of erosion for use in place of the annual climatic factor in the wind erosion equation was computed for 187 locations in the most severe wind erosion areas of the United States. From this data detailed maps of the United States were developed indicating lines of equal wind erosion climatic factor for each of the 12 months. A revised annual climatic map based only on those locations with measured wind velocity, temperature, and precipitation was also prepared. The monthly climatic factors for most locations had a range of values throughout the year and varied considerably from the annual value. For example, Midland, Texas, has a climatic factor of 100 in March, 60 in October, and an annual value of 80. This means that the potential erosiveness or, conversely, the requirements for wind erosion control for a given field would vary during the year even though soil, residue, and roughness conditions might remain constant. Use of the monthly factor will reduce the error in estimating erosion conditions and in designing wind erosion control practices. (SWC 8-el)

Portable wind tunnel tests conducted at St. John, Kansas, by the Wind Erosion Research Laboratory, Manhattan, Kansas, provided significant information on effects of winter wheat row spacing on wind erosion, which will be useful in improving the accuracy and applicability of the wind erosion prediction equation. With wind directions parallel to row direction, about 70 percent of the variability in soil loss data could be accounted for using curvilinear regression models with row spacing, surface roughness, soil cloddiness, and amount of residue as variables. Use of these variables in the same kind of regression model accounted for only about 50 percent of the variability in soil losses with winds perpendicular to row direction. Under conditions of average test site roughness, cloddiness, and residue, soil losses with winds parallel to row were nearly 11 times greater than losses with winds perpendicular to row. The effect of wheat row spacing was minimum on land of low general erodibility and when winds were perpendicular to row. Maximum effect, resulting in approximately 10,000-pound-per-acre larger soil losses from 10-inch spacing than from 8-inch spacing and from 12-inch spacing than from 10-inch spacing, occurred under highly erosive conditions and winds parallel to row. (SWC 8-el)

D. Practices, Structures and Systems for Modification of Soil Movement by Wind and Water

1. Barriers for wind erosion control. Further evaluations of drought hardiness and tenacity for growing under extremely adverse conditions were made in continuing field tests of plant materials having potential for single-row barriers at Garden City, St. John, and Colby, Kansas. Despite soil moisture deficiencies at all three locations that caused a general decrease in growth rate from last year, many of the plants still made substantial growth and survival was surprisingly good. Lombardy poplar and Russian mulberry remain the most promising trees, but this year's results indicate the honeylocust should be added to the list. Pampasgrass and bamboo again were the most promising grasses. Caragana and American plum should be included

with common lilac, bush honeysuckle, and tamarisk, which were listed last year as the most promising shrubs. (SWC 8-el)

Field trials at Big Spring, Texas, to evaluate the potential of forage sorghums, millets, and kenaf for use as wind barriers have shown that several of these annual crops can produce excellent barriers under favorable seasonal precipitation. The hybrid forage sorghum "Cropguard," kenaf, and pearl millet were the most effective barriers because they were fairly tall, did not lodge, and had good leaf retention. The forage sorghums "Beefbuilder," "Sweet Sioux," and "Little Indian," and a forage sorghum-sudangrass combination produced tall barriers but lost their leaves immediately after frost and lodged rather badly. However, these crops might have some potential for barriers if the upper portion of the plants were clipped. Preliminary data indicate some barriers may increase yields of cotton planted between the barrier rows. This could be due to barrier effects in altering the solar radiation budget between rows or to soil moisture effects. Additional research is planned to obtain more detailed information on these barriers and other crops such as yucca, sand bluestem, and blue panic grasses. (SWC 8-el)

2. Damage to plants by windblown soil particles. At Big Spring, Texas, continuing studies to evaluate abrasive injuries to cotton and grass seedlings from windblown sand showed that soil moisture, total amount of sand striking the plants, and duration of exposure are the major factors determining the recovery and growth of both these plants after exposure to abrasive damage. Tests on cotton seedlings showed that abrasive damage can cause a 4- to 5-week delay in bloom date, but if the cotton plants are not completely killed by abrasive injuries and if they have ample available water after exposure, they can recover and grow as well as undamaged plants. Abrasive flux of 0.10 gm./cm. width/second in a 900-cm./second (20 m.p.h.) wind for 10 minutes actually increased total plant production of side oat grama when exposed at the 6-leaf stage. This phenomena of increased production when exposed to slight abrasive injury has also been observed with green beans and cotton. Abrasive fluxes of 0.25 gm./cm. width/second for 30 minutes or 0.10 gm./cm. width/second for 60 minutes with a 1,350-cm./second (30 m.p.h.) wind were required to completely kill cotton seedlings and to severely reduce grass production. (SWC 8-el)

3. Contour and furrow systems. Runoff was high but soil losses were low from 37.15 inches rainfall in 1966 (EI = 264) on terrace-interval plots with 72.6 feet slope length and graded rows of 0.3 percent slope and 150-foot length at Holly Springs, Mississippi. These plots were on land slopes of  $2\frac{1}{2}$ ,  $4\frac{1}{4}$ , and 10 percent in corn with good management. Total runoff was 8.8, 10.4, and 11.7 inches and soil loss was 3.2, 5.0, and 5.5 tons/acre, respectively, on these slopes. The effectiveness of row ridges on sloping land was shown in a series of five intense rainstorms from May 1 to May 24 soon after the corn was planted and ridges were highest. The five rainstorms totaled 6.0 inches with 71 EI units. The losses from the  $2\frac{1}{2}$ ,  $4\frac{1}{4}$  and 10 percent slopes were 2.9, 3.4, and 3.3 inches runoff and 2.3, 3.6, and 3.8

tons/acre soil, respectively. Furrow capacity between the ridges was 1.83 inches for the  $2\frac{1}{2}$  and  $4\frac{1}{4}$  percent slopes and 1.58 inches for the 10 percent slope. Soil loss from a fallow plot on a 5 percent slope was 13.9 tons/acre for these same rains. (SWC 8-b1)

At Temple, Texas, an area of graded furrows again effectively controlled runoff and erosion and produced an above-average grain sorghum crop which was not appreciably more difficult to harvest than sorghum on adjacent flatland. Total runoff for the year from triplicated furrows averaged 1.1, 1.3, and 1.5 inches from 340-, 520-, and 930-foot rows, respectively. However, statistical analyses of all storm data showed no significant row length effect. Erosion data were incomplete because of equipment malfunction; however, during a storm on April 25 when the greatest amount of erosion occurred, soil loss averaged 0.95, 0.77, and 1.12 tons per acre from the 340-, 520-, and 930-foot row lengths, respectively. Grain sorghum yields were largest from the 340-foot rows, averaging 3,300 pounds per acre. The yields from 520- and 930-foot rows were almost identical, averaging 2,700 pounds per acre. The grain sorghum yields this year were reversed in trend from the oat yields last year, with maximum production being obtained from the longest rows. (SWC 8-10(e2) Rev.)

In a study of six corn tillage practices and their resulting geometric surface shapes at three locations in eastern South Dakota, no significant differences were found in corn yields. At two of the locations, 1966 rainfall was good to ideal, and at the third location, it was extremely dry. Therefore, the effect of surface water storage capacities for the various shapes showed no major differences. Little or no runoff occurred for any of the conditions. However, the listed and bedded treatments increased the amount of soil moisture in the top 4 feet of the soil profile at two of the three locations. Land-shape modification through tillage alone in subhumid regions may provide a simple method for combining moisture conservation and erosion control. (SWC 8-c4)

4. Deep profile modification. Soil profile characteristics that restrict root penetration often limit crop production under dryland conditions because plant roots are not able to extract water from as great a depth. Eliminating soil profile characteristics restricting rooting depth often increases the intake capacity of soils on steeply sloping lands, thereby minimizing runoff and erosion. The increase in crop yield as a result of more available soil water provides immediate economic benefits from expensive soil profile modifications. Data obtained near Rockford, Washington, indicate that disrupting the dense B horizon of Freeman soil resulted in 1 to 2 inches more water stored from winter precipitation, and the crop extracted 1 to 2 inches more water during the growing season as compared to normal plowing. Three-year mean alfalfa yields were increased 0.5 to 1 ton per acre and mean wheat yields were increased 10 to 14 bushels per acre when adequate fertilizer was provided. Yield increase can be attributed primarily to increased water storage and rooting depths. (SWC 8-f1)

5. Erosion control practices for construction sites. Woodchips applied at 6 tons per acre and anchored with asphalt emulsion at 150 gallons per acre provided adequate protection for spring grass seedings in newly constructed farm waterways in eastern Nebraska. Straw and hay mulches are subject to wind movement and require better anchorage than woodchips. The woodchips were moved by runoff during the 1966 season, but erosion was not significant. Woodchips have been shown to inhibit the germination of broadleaved weeds in earlier experiments. (SWC 8-8(d1))

Superior protection against erosion from simulated rainstorms on the 2:1 backslope (fill) of a conservation dam near Lincoln, Nebraska, was provided by mulches of asphalt emulsion (1,200 gallons per acre), woodchips anchored with asphalt emulsion (6 tons with 150 gallons per acre), jute net, prairie hay anchored with asphalt emulsion (1 ton with 150 gallons per acre), and a mat of excelsior and netting. Wood cellulose slurry materials were among the least effective erosion control treatments.

At Lincoln, Nebraska, runoff and rilling from simulated rainfall was controlled on bare plots by placing jute cords (1/16 in., 1/8 in., and 1/4 in. diameters) at 2- and 4-inch intervals across the plots. The jute was then sprayed with a narrow band of asphalt emulsion to bond it to the soil surface. The jute covered only about 5 percent of the plot surface but erosion (comparison to check) was reduced by 95 percent for an initial storm (2.5 inches in 1 hour) and 85 percent for a second storm (2.5 inches in 1 hour). Other plots were similarly treated with bands of asphalt emulsion alone. The bands of asphalt emulsion alone effectively controlled rilling and erosion for about an hour (2.5 inches per hour). Once the bands broke down, rilling and erosion increased. The effectiveness of surface detention and prevention of rilling rather than direct protection against raindrop impact alone for erosion control by a mulch is indicated. A muslin cloth suspended above other plots essentially prevented erosion. (SWC 8-8(d1))

#### E. Loss of Nitrogen in Runoff and Erosion

Nitrogen losses in washoff (water and soil) at Watkinsville, Georgia, were negligible where 200 lbs./ac. N was applied as ammonium nitrate to dry fallow Cecil soil with slopes of 5 to 11 percent. The maximum loss measured from a 10-year frequency simulated rainstorm was 2.6 lbs./acre or 1.3 percent of the amount applied. The losses were even less where the fertilizer was mixed with the soil. When a similar amount of N was applied to wet soil, the losses were 9 percent from a surface application, but only 1.5 percent when mixed with the soil. Losses were less from sod than from the fallow soil when the fertilizer was applied to dry sod, but were about equal when the fertilizer was applied on wet sod. There was a greater concentration of ammonium-N than of nitrate-N ions in the washoff. Nitrogen losses were closely associated with the amount of runoff. (SWC 8-b1)

In tests on steeply rolling Zanesville soil in southern Indiana, losses of surface-applied nitrogen (400 lbs. per acre) in runoff were relatively small even when rain was applied at high intensity. The greatest observed loss,

13 percent, resulted from 10 inches of intense rain applied in four storms over a 9-day period. However, nitrogen losses from ammonium nitrate applications were approximately twice those from urea applications, both on sod and on fallow. Losses from the ammonium nitrate treatments contained appreciable nitrate-N, though less than ammonium-N, whereas those from urea were primarily ammonium-N. This suggests that nitrogen carriers containing no nitrates offer an effective way to reduce nitrates in runoff from farmland. (SWC 8-c2)

F. Equipment and Techniques for Study of Runoff and Erosion

A study of the effect of sediment load on the calibration of 0.6-foot HS flumes at Morris, Minnesota, has indicated that runoff measurement errors up to 30 percent from the standard calibration curves may occur for these flumes when used to measure sediment-laden water. The error appears to be caused by changes in floor slope and elevation due to deposited sediment and not by changes in viscosity or density of the measured water. HS flumes are widely used in runoff and erosion measurements, so knowledge concerning their characteristics is essential for accurate research results. (SWC 8-c4)

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AREA 9: MOISTURE CONSERVATION FOR THE EFFICIENT AND EFFECTIVE  
USE OF PRECIPITATION ON CROPS AND RANGELANDS

Problem: One of agriculture's major plagues in the United States is recurring drought. The Northeastern States suffered from extensive drought during the 3-year period 1964 to 1966. In 1965, wheat yields in the Northwest and the Great Plains were reduced by prolonged drought. Tree ring studies conducted in Nebraska show that in 269 of the last 748 years, there was sufficient drought to adversely influence crop production. Weather records at several locations in the Plains show that precipitation is below average 50 percent of the time.

During most drought years, 1 or 2 inches of water will make the difference between a crop and a failure. If some means of reducing the large loss of water by evaporation or of reducing the water used in transpiration were available, the precipitation received would be more than adequate to support good plant growth and still provide sufficient water for other uses.

The research is directed towards the development of methods for increasing the infiltration of water into the soil profile and decreasing the evaporation of soil water by physical and chemical means.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of moisture conservation, utilizing soil physicists, soil chemists, soil microbiologists, and agricultural engineers. At all locations, the work is done cooperatively with the respective State experiment stations.

The Federal scientific effort devoted to research in these areas totals 15.39 man-years. Of this total, 10.09 are devoted to factors influencing moisture storage; 3.10 to factors affecting the loss of water by evaporation; and 2.20 to factors influencing the use of moisture by crops.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 28 scientific man-years is devoted to this area of research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Factors Influencing Moisture Storage

1. Tillage. Researchers and farmers have recognized that the amount of water entering the soil is closely associated with the various physical conditions at or near the soil surface. At Morris, Minnesota, simulated rainfall was applied at the rate of 5 inches per hour to various soil tillage treatments on Barnes clay loam, Barnes loam, and Nicollet sandy loam to determine what surface soil conditions enhance soil profile water storage. The total water intake from the time of rainfall initiation to the time of initial runoff on freshly tilled, bare surfaces was two to four times greater for rough plowed surfaces than for smoother surfaces (i.e., plowing, disking, and harrowing). Water intake on tilled soils was highly correlated with random soil roughness and with soil porosity. After runoff began, the rate of water intake was frequently not significantly different between the rough plowed and the plow-disk-harrow treatment. Apparently, by the time runoff began, surface sealing was sufficient to mask our infiltration differences during the runoff period, even though roughness and porosity differences existed. The greater total water intake on the rough plowed surfaces resulted from prolonged time to initial runoff. (SWC 9-c1)

The importance of dense layers at the 16- to 22-inch depth in Great Plains soils on moisture storage and crop yields has never been resolved. During the past year, tillage studies were initiated at Bushland, Texas, on a Pullman soil with a very slow permeable clay subsoil. Results show that the water storage in the 6-ft. profile was increased by 50 percent by deep plowing. Although moldboard plowing to a depth of 16 inches did not completely penetrate the dense layer, it was nearly as effective as plowing to 24 or 32 inches. (SWC 9-e1)

Previous experiments conducted in the Great Plains have shown that wind erosion on land tilled with sweeps, commonly referred to as subtillage, has been consistently less than that on land tilled with the one-way plow. Soil moisture data collected at Bushland, Texas, on subtilled and one-way plowed treatments during the past season have shown that more than one-half inch of additional water was stored in the 6-ft. soil profile under subtilled treatments. Associated with this increased moisture was an increase in wheat yields of over 3 bushels per acre as compared with yields on the one-way treatments. (SWC 9-e1)

2. Fallow methods. In the continuing search for more efficient farming systems in the dryland wheat region, the agronomic aspects of chemical fallow are being reevaluated. In studies at Pendleton, Oregon, the influence of herbicides on soil nitrification is being studied. Preliminary results showed that greater soil nitrification occurred in chemical fallow as compared with conventional, providing there was adequate soil moisture in the late spring. (SWC 9-f1)

3. Land forming. During the past decade, many studies have been conducted in the Great Plains to evaluate the influence of leveled benches with and without contributing areas on the utilization of precipitation. An analysis of the data indicates that contributing areas in the Northern Plains yield little additional water to the benches, but in the Central and Southern Plains, the benches obtained considerable additional water from the contributing area.

Results from experiments conducted during the past season at Akron, Colorado, showed that the total dry matter yield on a level bench with no contributing area was 600 pounds per acre greater than on a fallowed area, but the yield on a bench with a contributing area was 1600 pounds per acre greater than on the fallow area. Dry matter yields increased from 1300 to 6500, 800 to 5100, and 1800 to 2800 pounds per acre for forage sorghum, alfalfa, and corn, respectively, on the level benches as compared with adjacent fallowed plots. These and other data collected in the Great Plains indicate that forage crops give a greater response to the harvested water than cereal crops do. (SWC 9-d1)

At Bushland, Texas, the 10-year average annual yield on conservation benches with contributing watershed was 2260 pounds of grain sorghum per acre, as compared with 1640 pounds on a bench without a watershed. The conservation benches produced a crop every year, whereas on the wheat-sorghum-fallow sequence a crop was grown only 2 years out of 3. (SWC 9-e1)

At Riverside, California, concentrating rainfall with level bench terraces failed to increase barley yields or water-use efficiency. Concentrating all of the rainfall onto one-half of the land area by means of complete runoff from the other half did allow continuous cropping, but successful use of the runoff system required that water be diverted from the plots at planting time and during the early growth stages. In 1966, an above-average rainfall year, planting of barley on the benches was delayed for approximately one month because of excess runoff water. This late planting reduced the number of tillers and probably reduced the extent of the root system. These results emphasize that the use of level bench terraces on these and other low water-holding capacity soils may not be feasible. If these water control structures are used, it is important to provide means for diverting water from the area after high-intensity rain. (SWC 9-g1)

4. Runoff inducements. The level bench studies have pointed up the need for harvesting the water from some areas in order to profitably produce a crop in another area. During the year the search has continued at Fort Collins, Colorado, for soil amendments that might be economically feasible to use as water repellents to increase the water collected from the contributing areas. Measurements of runoff from plots treated with various chemicals showed that sodium chloride (ordinary salt) was still persistent a year after treatment, whereas the effect of sodium phosphate and sodium silicate had vanished. (SWC 9-d1)

The soils of many dryland areas are too permeable because of a sandy texture to obtain much runoff from a contributing area. Laboratory studies at Fort Collins, Colorado, concerned with evaluating the effect of various soil textures on infiltration have shown that soils with 75 to 90 percent sand have high infiltration. If small amounts of clay (10 to 20 percent) were added to the sand, a hard, cemented crust with a very low infiltration rate formed. If the sand content was above 50 and below 75 percent, a stable crust without cracks was obtained. These data are of value to those interested in obtaining a low-cost material that will increase the water yield from a watershed. (SWC 9-d1)

Several soil sealants were evaluated on three soil types at Akron and Nunn, Colorado. The precipitation runoff was 92 percent from asphalt, as compared with 61 percent from plastic and 25 percent from the untreated areas. However, asphalt proved to be impracticable because of excessive cracking. (SWC 9-d1)

5. Soil management. A need for information on the factors that determine winter moisture conservation continues in the Northern Great Plains. A summary of 6 years of data on the effect of stubble on snow deposition, soil temperature, and runoff at Mandan, North Dakota, has shown that snow depth was directly related to stubble height. Stubble had no insulative effect, in that the frost depths were the same under all heights. The spring melt started first on the areas with high stubble. Data from these studies indicate that stubble management can conserve winter moisture. (SWC 9-d1)

In a continuing study at Akron, Colorado, to determine the proper spacing of a snow barrier, results showed that soil water storage varied from 5 inches, 20 feet leeward from the snow fence, to 1 inch, 60 feet away. Grass production 25 feet from the fence was twice as high as at a distance of 55 feet away. Information collected from these studies have made it possible to design an artificial or crop barrier system that will trap most of the snow falling on the area. (SWC 9-d1)

## B. Factors Affecting the Loss of Water by Evaporation

1. Type of drying. To predict the water requirements of crops, it is necessary to determine the loss of water from the soil by evaporation. At Fort Collins, Colorado, results of studies concerned with testing the adequacy of the diffusion equation for describing evaporation show that the evaporation of water from soils over a 38-day period was the same whether by wind or radiation. During the first half of the cycle, the rate was 20 percent greater on the wind treatment. The radiation treatment caused a lower water content in the surface soil. These data, though preliminary, indicate that it should be possible to use the diffusion equation to describe evaporation losses. (SWC 9-d1)

In another study at Fort Collins, Colorado, concerned with reducing evaporation, a 1-inch-thick gravel mulch increased ground water storage by a foot of water a year. This inexpensive method of control made it possible to obtain water for as low as \$5 an acre-foot. (SWC 9-d1)

2. Stubble mulch. The question of how effectively stubble mulch conserves water in the Great Plains has long been debated by scientists and farmers. In soil moisture studies conducted at Akron, Colorado, over a 2-year period, initial straw rates of 1500, 3000, and 6000 pounds per acre applied to wheatland resulted in dry matter yields of 2910, 3510, and 3740 pounds per acre. A hailstorm in late May made it impossible to accurately determine any grain response. Yields on clean-tilled plots and the 1500-pound-per-acre mulch plots were the same. The residue from an average wheat crop in this area is less than 3000 pounds per acre. (SWC 9-d1)

Soil water storage at Sidney, Montana, on straw-mulched treatments was 7 percent higher than on a bare soil. Winter wheat survival also was higher on the mulched plots. (SWC 9-d1)

In an attempt to reduce evaporation in a greenhouse study at Bushland, Texas, a layer of crop residue was placed on and below the soil surface. Evaporation reduction was greatest with the surface-applied mulch. Moisture distribution in the soil was markedly affected by placement of residue in relation to the soil surface. The water content was highest immediately beneath the residue layers on both the surface and covered residue treatments. (SWC 9-e1)

The potential for decreasing soil evaporation by manipulation of surface residue is also being studied at Mandan, North Dakota. Preliminary data indicate that limited quantities of residue are most effective when applied in strips. The data emphasize the importance of time of drying. If the drying time is long enough, the evaporation from any surface residue will eventually equal that from a bare soil. Thus residues are effective if a wet soil is subjected to a high evaporation rate only for short periods of time. Although these results do not give a complete understanding of the influence of the amount of cover on the loss of soil water by evaporation, they do represent a good beginning and help to define areas where future emphasis should be placed. (SWC 9-d1)

3. Unsaturated conductivity. In an attempt to evaluate the significance of moisture flow in the vapor phase, a solar still was installed over water and over a soil moistened to field capacity at Mandan, North Dakota. For a 116-day period in 1966, the average condensation over water was 60 mm. per day, as compared with 52 mm. per day over soil. These data emphasize the importance of unsaturated flow in the loss of water from soil by evaporation. (SWC 9-d1)

Data collected from dryland field experiments over the past two decades have suggested that appreciable water might be moving down through dryland soils, rather than out of the soil by evaporation. The presence of sizeable amounts of nitrates and herbicides deep in the soil profile is evidence of this movement. Results collected with a new technique developed at Akron, Colorado, for quickly determining unsaturated conductivity in soils, show that water movement through dryland soils to depths beyond the rooting zone averaged more than an inch a year. These results agree with the amount of water that hydrologists have estimated to be yearly inflow to the water table, and indicate that the bulk of the inflow comes from water moving through the soil profile as unsaturated flow. (SWC 9-d1)

In a PL-480 study in Israel concerned with determining the extent that evaporation losses can be minimized by modifying the soil surface, results showed that the predicted loss from Gardner's and Anat's theories was far greater than those measured, especially, over shallow water tables. Results obtained from drying layered profiles revealed that cumulative water loss was dependent upon the size range of aggregates and the depth of the surface layer. Aggregated top-layers lost water more rapidly than corresponding depths of unaggregated soil but effectively conserved the water of the underlying soil. Future studies will be concerned with field experiments and laboratory trials to further test the evaporation theories. (A10-SWC-32)

#### C. Factors Influencing the Use of Moisture by Crops

1. Surface color. Studies have continued during the year at Fort Collins, Colorado, to determine the influence of soil color on corn growth. Over a 3-year period, average yields of corn grown adjacent to black concrete were 3315 pounds per acre, as compared with 2287 on corn grown adjacent to a white concrete surface. This yield increase was due to earlier emergence, faster growth, and earlier maturity on the black treatment. Higher reflection of light to the plants caused a higher transpiration rate on plants growing on the white surface as compared with the black surface. However, the chlorophyll content of the corn leaves growing adjacent to the black surface was 20 to 50 percent higher than that of leaves growing over the white surface. (SWC 9-d1)

The response of corn to a "light rich" environment was investigated over a 2-year period at Urbana, Illinois. Grain yields were greatly increased by growing plants in front of large reflectors. Yields on the "light rich" treatment reached 370 bushels per acre. These studies suggest that corn does not become light saturated at ordinary levels encountered in the field. Therefore, light is the primary ecological factor limiting the present grain yield potential of this crop. (SWC 9-cl)

2. Rangeland seedbed preparation. Studies have continued at Nunn, Colorado, in an attempt to develop a soil and water management system for successfully

revegetating depleted rangelands and abandoned cropland. Results over a 3-year period showed that it was not possible to store enough water in the seed zone to allow grass establishment by any of the fallow methods studied. (SWC 9-d1)

3. Crop species. At Madison, South Dakota, the yields of corn and grain sorghum with various management systems have been compared during wet and dry years. Grain sorghum yields were appreciably increased by high plant population in moisture favorable years, but were the same at low and high populations during a dry year. In contrast, corn grain yields increased slightly when population was increased from 14,000 to 28,000 plants per acre in a favorable year, but were reduced drastically by the higher population during a dry season. In 1966, an average rainfall year, maximum corn grain yields were 3038 pounds per acre, as compared with maximum grain sorghum yields of 4964 pounds. These data indicate the grain sorghum is better adapted to this area than is corn. (SWC 9-cl)

4. Evapotranspiration of crops. Farmers and action agency personnel have known for some time that certain crops are much better adapted to the Great Plains than others. Results from evapotranspiration field studies at Akron, Colorado, conducted over a 2-year period with several crops, have shown that evapotranspiration in oat fields is considerably higher than could be accounted for by solar energy or soil heat storage. On examination of the data, it is apparent that oats extract sensible heat from the surrounding air to a much greater degree than does sorghum or sudangrass. Weekly evapotranspiration from oats was greater than evaporation from a free water surface for 3 weeks in 1966, and 8 weeks in 1965. These data suggest that oats are not well adapted to the eastern Colorado area. (SWC 9-d1)

In these same studies, information was collected to delineate the moisture loss from soil before various crops cover the soil surface. Results show that before above-ground dry matter production of consequence began, evaporation of water directly from the soil was 3 inches for sorghum and 5 inches for wheat. Evaporation during the growing season accounted for 45 percent of the water used by a wheat crop, and 65 percent of that used by sorghum. During peak growing periods, transpiration accounted for 75 percent of the water used by wheat and sorghum. These data, incomplete as they are, suggest that the real challenge still is how to reduce evaporation losses during the time a crop is produced. (SWC 9-d1)

In a continuing search for simple methods of estimating evapotranspiration, net radiation soil heat flow, temperature gradients and vapor pressure gradients were measured at Akron, Colorado. Results show that all of these measurements are needed to accurately predict evapotranspiration as directly measured by lysimeters. In all cases, the values for sorghum were underestimated. Data from these studies are supplying information badly needed to develop soil and water management systems for conserving precipitation received. (SWC 9-d1)

Evapotranspiration data from rangeland at Bushland, Texas, emphasize the low return for water falling on range sites. Native shortgrass dry-matter yields were only 200 to 300 pounds per acre during a year when the rainfall was 9.2 inches. The dry-matter production of cultivated crops receiving the same amount of precipitation was several times higher. (SWC 9-e1)

The effectiveness of fertilizer for increasing productivity of and water-use efficiency by crested wheatgrass was underscored by results from Mandan, North Dakota. Rainfall distribution was unfavorable for forage production in 1966, and without fertilization, 8.2 inches of available water resulted in 600 pounds of forage per acre. In contrast, over 2000 pounds of forage was produced per acre with the same amount of water when fertilizer was applied. However, grass stands are beginning to deteriorate after 5 years of N fertilization, and ammonium-containing fertilizers have lowered soil pH as much as one unit. (SWC 10-d3)

A hydraulic lysimeter was used in studies at Riverside, California, to determine evapotranspiration rates from dryland barley in a winter rainfall climate. Daily readings over a 98-day growing season showed a low average daily ET rate of 0.04 inch during the 21-day period from emergence to tillering. From tillering to heading, or flowering, the rate was 0.16 inch per day and from heading to the soft dough stage, 0.20 inch per day. The latter two periods are equivalent to 50 percent of the growing season but accounted for 75 percent of the total evapotranspiration. As the barley crop ripened, ET declined to an average of 0.08 inch per day. Evapotranspiration increased as much as 200 percent for a period of 2 days following water applications. Evapotranspiration was linearly correlated with average daily temperature during a period of relatively constant leaf area. Over a range of 55° to 75° F. average daily temperature, ET increased 0.15 inch per degree rise in temperature. No relationship between ET and relative humidity for the same period was evident. (SWC 9-g1)

5. Rooting ability of wheat. Most data collected from dryland wheat areas are difficult to interpret because of the erratic response of the crop to moisture. Wheat studies at Bushland, Texas, which included an extensive examination of roots, showed that a 2-inch rain shortly after seeding enhances the development of an extensive root system. The extensive root system enabled the wheat to remain viable until a rain occurred in early June. This rainfall pattern, coupled with favorable temperature and humidity, made it possible to produce a normal wheat crop on less than 4 inches of precipitation, plus the stored soil moisture at seeding time. At maturity, the roots of the border plants extended completely across a 100-inch noncropped strip. (SWC 9-e1)

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AREA 10: SOIL PROPERTIES, PROCESSES, AND MANAGEMENT  
IN RELATION TO THE CONSERVATION AND EFFICIENT  
USE OF LAND AND WATER RESOURCES

Problem: The soil is the source of the nutrients required for plant development. When chemicals are applied to the soil, they usually react with the soil before the plant uptake process begins. The nutrient ion finally is found in the top of the plant where it performs its metabolic function. To reach this end point, the ion passes through various chemical reactions, most of which are not understood.

Soil tilth and structure control many of the responses of the plant to soil management. Too often, visual improvement of the physical properties of the soil has been observed in the field, yet these physical attributes cannot be quantitatively described because of a lack of methods and procedures. The research progress on soil tilth is hampered by a lack of understanding of the forces involved in holding soil particles together in stable crumb structure. If our understanding of the factors was improved, our scientists could develop practical methods for exerting a real influence on the structure of soils.

Recent improvements in the processes important in the nitrogen fertilizer industry have been or will be reflected in increased production and lower prices to the consumer. With the rapidly expanding use of N fertilizers, overapplication may be expected to become increasingly prevalent because little is known regarding intrinsic N requirements associated with specified levels of maximum production for most of the major crops. Among the problems that may arise from overuse of N are (a) reduction in crop quality, (b) possible accumulation in ground and surface water, and (c) waste of some important natural resources used in synthesis of N fertilizers.

In recent months, concern about water pollution from small quantities of soluble nitrogen and phosphorus has increased. Increasing the nutrient content of surface waters results in objectionable growth of algae and larger water plants (eutrophication). Fertilization of agricultural lands is suspected as one of the contributors. However, the amounts of nitrogen and phosphorus reaching waters that can be attributed to fertilization of agricultural lands are as yet largely unknown.

The amounts of insecticides and herbicides being used on agricultural lands continue to grow. Most of these compounds are applied to the soil, or ultimately reach the soil. The adsorption and persistence of these compounds in soils must be understood if soil pollution is to be avoided. World population and food supplies are causing concern, and experts predict that food shortages are inevitable. Our only hope for meeting the world food requirements lies in new technology developed through research.

## USDA AND COOPERATIVE PROGRAM

The Division program in this area involves microbiologists, chemists, physicists, and plant physiologists working on basic and applied problems associated with developing principles for soil and water conservation. The Federal scientific effort devoted to this research totals 84.06 professional man-years. Of this number, 23 are devoted to nutrient requirements--uptake and balance; 28 to soil chemical properties; 24.06 to tillage, residue management, and cropping systems; and 9 to soil microbiology.

### PROGRAM OF STATE EXPERIMENT STATIONS

A total of 262\* scientific man-years is devoted to this research.

### PROGRESS      USDA AND COOPERATIVE PROGRAMS

#### A. Nutrient Requirements--Uptake and Balance

1. Nitrogen recovery and movement. Public concern about the role of N in stream and lake eutrophication has created a new interest in the efficient use of N. At Huntley, Montana, studies continued on the recovery of residual fertilizer N under irrigation. In 1962 and 1963, sugar beet and bromegrass plots were fertilized with 100, 200, and 400 pounds of nitrogen per acre, and the residual effects were measured in 1964 and 1965. Barley was grown on these plots in 1966 to further evaluate the recovery of residual fertilizer nitrogen. The residual nitrogen on the 100- and 200-pound-per-acre N plots increased barley yields only slightly, but yields increased significantly on plots that had received 400 pounds of nitrogen per acre. Total recovery of the fertilizer nitrogen during the 5-year study was 95, 86, and 64 percent for the 100-, 200-, and 400-pound nitrogen fertilizer rates, respectively. (SWC 10-d2)

At Mandan, North Dakota, the recovery and movement of nitrogen from various fertilizer sources were studied on a Parshall fine sandy loam. The nitrate contents in a 48-inch profile under bromegrass were unaffected by fertilizer treatment, but high rates of nitrogen significantly increased the nitrate content of soil profiles under corn. These data indicate the need for additional studies to develop efficient systems for applying N. (SWC 10-d2)

2. Mineralization of nitrogen. The large quantities of nitrogen and other elements locked in the organic fraction of the soil greatly influence the fertilizer nitrogen requirements of crops. In addition, the physical, chemical, and biological reactions in soils are directly related to the organic fraction. In a continuing fundamental study at Corvallis, Oregon,

\*Under Long Range Study outline, fertility work on specific crops--formerly reported in this area--now reported under crops concerned.

on the chemical constituents of soil organic matter, comparative results indicate that as far as the amino nitrogen constituents (a major fraction of total soil nitrogen) are concerned, the amino acid spectrum of soil hydrolyzed directly with strong acid (6 N HCl) is similar to the amino acid spectrum (after hydrolysis) of soil organic matter extracted with mild chelate resins. The overall elution patterns and relative amounts of each amino acid in proportion to the total N were very similar by both methods. Direct hydrolysis of soil with strong acid (6 N HCl) yields two to four times more amino acids, is more rapid, and is less variable than the hydrolysis of soil organic matter extracted with mild chelates. In addition, several organic matter pre-separation and extraction steps are avoided. Hydrolysis times of 6 to 18 hours or less are preferred to avoid progressive degradation of several important amino acids that occurs with longer hydrolysis time. These data enlarge our limited knowledge of soil organic matter chemistry. (SWC 10-f3)

The importance of nitrogen content on wheat straw decomposition rates is under study at the Snake River Conservation Research Center, Twin Falls, Idaho. Results indicate that the decomposition rate is not influenced by the nitrogen content of the straw when sufficient nitrogen is added to the soil. When straw containing 2 percent nitrogen was added, decomposition rates in the laboratory were directly proportional to the nitrogen content of the soil, and almost no residual nitrate was found in the soil after 80 days' incubation. Straw with the same nitrogen content buried in field plots decomposed at a uniform rate regardless of the previous nitrogen fertilization of the plots. These data are of value in predicting the N requirements of soils in which crop residues have been incorporated. (SWC 10-f2)

Results from a continuing study at Beltsville, Maryland, concerned with describing the mechanism involved in the fertilizer induced uptake of soil N have shown that the first increments of N extracted with sodium pyrophosphate were easily mineralized. More intensive extraction revealed that the more difficultly extractable N was extremely resistant to mineralization. These data suggest that the methods used today to obtain soil N indexes are unreliable. (SWC 10-aB2)

Soil scientists have expressed concern about the exploitation of the organic matter in cultivated soils and have predicted that unless systems are developed for halting this decline, lower crop yields can be expected. At Shenandoah, Iowa, an experiment on Marshall silty clay loam has shown that the organic carbon content of a soil, after 12 years of residue application, increased proportionately with increasing residue applied. The organic carbon content was 1.42 percent on the check (no residue application) and 1.99 percent on the 8-ton-per-acre-per-year residue application (alfalfa and corn stalk residues). There was no difference in organic carbon buildup due to application of different kinds of residue (corn stalks, alfalfa, sawdust, oats straw, brome grass). (SWC 10-c2)

Evaluation of changes in soil properties resulting from 26 years of varying residue management practices and cropping systems on Pullman silty clay loam at Bushland, Texas, revealed that organic matter, wet aggregate stability, dry aggregate size distribution and stability, and total nitrogen content were affected by tillage treatment and cropping system. Continuous wheat was superior to a wheat-fallow-wheat cropping system in maintenance of organic matter, total nitrogen, and aggregate size. Size distribution and stability of the dry aggregates were related to the soil organic matter content. (SWC 10-e1)

In the Imperial Valley, California, cropping systems that included alfalfa, manure, or Coastal bermudagrass resulted in higher residual organic matter and nitrogen contents in the surface foot of soil than those that included only row crops grown at various nitrogen levels. With all rotations, returning crop residues increased organic matter and nitrogen contents in the surface foot of soil. Below the 1-foot depth, the soil was affected very little by cropping practices or residue management treatments. (SWC 10-g1)

At Temple, Texas, after a 12-year period, cropping systems of 2 years of fescue and 1 year of row crop, or the use of sweet clover with a row crop every other year, had increased soil organic matter, aggregate stability, water intake, and internal drainage of Houston Black clay compared with continuous row crop. (SWC 10-e1)

Results of the studies discussed indicate that residues returned to the soil increased the organic matter. However, the level at which organic matter is maintained is determined by the cropping systems that bring the greatest economic return.

The mineral and organic soil fractions are being studied in a Pl-480 project in Poland. Results show that the treatments used had little influence on the carbon, nitrogen, and colloidal contents in the soil. Excellent techniques were developed for making thin section soil microphotographs. Cell walls and humus deposits were easily distinguishable in these photos. (E21-SWC 2)

3. Nutrient requirements of various crops. Although the climate in the Southeast is ideal for forage production, the forages are generally of low quality. In a study at Watkinsville, Georgia, concerned with determining the effects of fertilization and management on Coastal bermudagrass quality, the results for a 3-year period show a consistent decline in forage production for those treatments clipped at 2- and 4-week frequencies but little change on the treatments clipped at a 6-week frequency. This decline with more frequent clipping appears to be related to depleted root reserves. Other than the expected nutrient increase in forages associated with fertilization, management appeared to have little influence on forage quality. (SWC 10-b3)

In most Latin American countries, the yields of yams and other root crops used as a source of carbohydrates is quite low. In Puerto Rico, several rates of six sources of nitrogen were applied to yams and manioc. Yields of these root crops were increased severalfold by the use of high rates of N fertilizer. All sources of N were equally effective except ammonium sulfate. The acidifying properties of ammonium sulfate made it an undesirable N source for these soils. (SWC 10-b3)

Frequently, the production potential of water-spreading systems is not achieved because of low soil fertility. On the clay soils at Newell, South Dakota, yields of brome grass, Western wheatgrass, and pubescent wheatgrass were increased from two- to four-fold by one or more floodings in a water-spreading system. However, to take full advantage of water diverted from nearby areas, nitrogen fertilizer had to be applied. On areas flooded once or twice during spring and early summer, 80 pounds of N per acre increased forage yields by 1500 to 2000 pounds per acre. These results in combination with results from watershed studies will furnish the basis for economic evaluation of water-spreading systems. (SWC 10-d3)

At Fort Collins, Colorado, results showed that plant metabolism of nitrogen is closely related to plant sulfur content. Utilization of N by wheat, corn, and beans was severely limited when S level in soil was low. As a result of S deficiency, nitrates, amides, and amino acids accumulated in plant parts. Adding more N did not increase yields or protein levels. Approximately 1 part of S for each 10 to 15 parts of N in plants was required for efficient N metabolism. These data suggest that the sulfur status of soils and plants must be closely watched if maximum yields of most crops are to be obtained in the Great Plains. (SWC 10-d3)

When many of the soils were first irrigated in Idaho, potato yield and quality were at a maximum. With continued cropping, both the yield and quality decreased until it became unprofitable to produce the crop in certain areas. Studies at Twin Falls, Idaho, indicated that available nitrogen in excess of potato plant needs caused a proportion of the harvested tubers to be rough, immature, spindly, and pointed on one end. The degree of these undesirable effects intensified, and a greater percentage of the tubers was affected with increased excess available nitrogen. Future studies will be concerned with evaluating a slow-release N source. A potato tissue test will be developed to predict excess N level. (SWC 10-f2)

It has been known for sometime that excess N can reduce the sugar content of sugarbeets. Data collected from field studies at Twin Falls, Idaho, show that maximum sugar production and maximum tonnage of beets occurred at different nitrogen levels. The data indicated that the N levels routinely used on sugar beets are too high for maximum sugar production. (SWC 10-f1)

In an experiment at Brawley, California, to determine the effect of excessive rates of nitrogen on the growth characteristics, yield, and fiber properties of skip-row planted cotton, production was maximum at 400 pounds N per acre with no increases or decreases at higher rates of application up to 600 pounds per acre. Application of all nitrogen fertilizer by May 21 was found to be most desirable. Late applications interfered with early harvest. Data for petiole nitrate-nitrogen levels associated with maximum production showed that nitrate-nitrogen levels should remain above 2,000 p.p.m. until mid-September. At maximum yield levels, cotton used less than 50 percent of the fertilizer nitrogen. Nitrogen applications did not affect fiber length, micronaire, or elongation characteristics, but fiber strength was below normal in the N-deficient cotton and was consistently above normal in plots receiving late-season nitrogen applications. The results of this experiment indicate that petiole nitrate-nitrogen analyses should be used to determine whether additional nitrogen is needed in midseason. (SWC 10-g1)

At Weslaco, Texas, studies have continued in an attempt to develop a method for predicting the N fertilizer needs of soils. Results obtained to date suggest that the degree of effectiveness in predicting yield response to N as a function of soil nitrate or mineralizable N depends on the season of the particular year that the crop is grown. Progress on the important problem of predicting the N requirements of crops has been extremely slow. (SWC 10-e2)

In another study at Weslaco, the effect of soil water on N response was evaluated. Preliminary analysis of the data show that the evapotranspiration and water requirements of cabbage were significantly affected by the N fertilizer level. (SWC 10-e2)

The influence of plant nutrients on the salt tolerance of plants has not been sufficiently elucidated. Yield responses of plants growing in a saline substrata have been determined in a PL-480 project in Israel. Clover plants adequately supplied with phosphorus were more tolerant of salinity than those plants not receiving phosphorus fertilizer. With this crop, nitrogen was only of secondary importance. (A10-SWC-1)

4. Ground water pollution by nitrates. The concern about ground water pollution by nitrates from nitrogen fertilizer and runoff and leaching from feedlots prompted the Division to study the distribution of nitrates and other pollutants under fields and corrals of the Middle South Platte Valley of Colorado. Native grass fields, as a rule, did not show nitrate accumulation in the soil profiles, and profiles under irrigated alfalfa fields generally contained insignificant amounts of nitrates. Small accumulations of nitrates below the root zone were found on cultivated nonirrigated fields. Significant quantities of nitrates were found in most of the cores taken from irrigated fields being cropped with row crops or cereal grains. The

amounts of nitrate nitrogen found in corral cores were extremely variable, ranging from almost none to more than 5,000 pounds per acre in a 20-foot profile. Nitrates were found in most water table samples analyzed. In many cases, the concentrations exceeded the 45-p.p.m. nitrate level considered safe by the U. S. Public Health Service for potable water. The ground water from beneath corrals was no higher in nitrates than under irrigated fields. Water samples from beneath several corrals contained high amounts of carbon and ammonia and had an offensive odor. The bacterial counts under corrals were also considerably higher than under other areas, especially at the lower depths. These findings indicate some accumulation of nitrates in ground water is occurring from the corrals and cultivated fields, but more studies are required before the significance of this accumulation can be assessed. (SWC 10-d2)

Marked variations in microbial populations, some surprisingly high, were encountered in examinations of the deep core samples. At many drill core sites, there appeared to be a higher microbial population at or just immediately above the ground water table. There was little evidence of any appreciable nitrifying population below the surface foot of soil. The microbial flora existing in the deeper profiles differs qualitatively from that at or near the soil surface. This strongly suggests that a deep soil flora is developing in situ. (SWC 10-d2)

Nitrates in runoff water from treated watersheds at Coshocton, Ohio, were severalfold higher than those from untreated sites. Limiting sampling indicates that a feedlot located on one of the watersheds did not contribute significantly to the pollution of the stream in which the drainage collected. (SWC 10-43(aB13))

5. Micronutrients. The yield of grain sorghum in the Great Plains is frequently reduced by iron chlorosis. Of the 51 varieties of sorghum screened for iron chlorosis resistance in the greenhouse at Bushland, Texas, sweet sudan and honey sorghum were the most resistant. When the iron deficiency was corrected by adding iron chelate or sulfuric acid, the sorghum responded to P fertilizer. (SWC 10-e2)

The yield of Gaines wheat grown near Pendleton, Oregon, continues to show benefit from sulfur applied as gypsum in 1960. In a wheat-pea annual cropping system, 15 pounds of sulfur per acre has furnished adequate sulfur for three pea crops and four wheat crops. The average yield increases for the four wheat crops resulting from the sulfur application have been 4 bushels per acre. (SWC 10-f2)

Results from an experiment conducted at Prosser, Washington, to determine at what concentrations in the soil zinc may be toxic to plants, show that a 100-pound annual zinc treatment applied over a 3-year period caused no visual or measurable injury to corn or sorghum. These results indicate that there is no immediate danger of polluting these soils by applying zinc at recommended rates (12 pounds every 3 years). (SWC 10-f1)

Results from a PL-480 project in Israel concerned with predicting the availability of zinc to various crops by soil analysis show that the fixation of zinc in some soils was rapid and complete; while in others, only moderate amounts were slowly fixed. Zinc availability was higher in rendzina soils than in loess soils. (A10-SWC-12)

6. Phosphorus diffusion and uptake. If accurate predictions of the phosphorus requirements of various crops are to be made, the ion activity around the plant root must be defined. In research at Fort Collins, Colorado, a fivefold difference in rate of P uptake from three soils at the same concentration of P in solution could be explained by variations in diffusion. The uptake of P calculated by a diffusion equation agreed closely with the observed uptake. The diffusion equation took into account the differences between soils in diffusion coefficients and capacity of the solid phase to renew the soil solution as the roots removed P. The effect of water on the uptake of P from soils has been measured by a new, more accurate technique. Water tension was varied from 1/3 to 3 bars on three soils, each at four levels of available P. The diffusion coefficients,  $D_p$ , for P varied with the volumetric water content. When uptake of P was plotted as a function of  $D_p^2$ , a curvilinear relationship was observed, which indicated that the uptake of P by roots was more efficient with an increase in water. Diffusion of P did not fully account for the uptake of P. This result suggests that physiological changes in the roots may have been induced by the lower water content. The concentration of P in various soils as measured in 0.01 M  $\text{CaCl}_2$  could not be interpreted accurately in relation to plant response. Instead, the concentration of P in a saturation extract is considered to be a better way to measure the concentration and relate it to plant response. (SWC 10-d1)

In a PL-480 study in Israel concerned with finding more efficient ways of predicting phosphorus requirements of various soils and developing better methods for applying this fertilizer, results show that the residual soil phosphorus contributed less to the plants than that freshly applied. Soil analyses for extractable phosphorus by various methods showed a definite increase due to fertilizer treatment. (A10-SWC-22)

In another PL-480 study in Israel, the fixation of phosphorus is being evaluated in different soils which have received various management treatments. Results show that the fixation of phosphorus is controlled by the time and method of applying the fertilizer and type of sinks. The sinks are determined by the soil properties. These data will lead to improved methods of applying fertilizer and serve as a guide to experimental design. (A10-SWC-38)

7. Subsoil nutritional needs. In the past decade, many field experiments have been conducted concerned with restoring the productivity of subsoils exposed by land forming or erosion. Data from these studies have shown that normal production on these areas can be restored if adequate fertilizer and lime are applied.

In recent years, the public has become concerned about large scar areas left by strip-mining operations. During the past year, studies have been initiated near Sandersville, Georgia, on an area that has been stripped to a depth of 100 feet to determine the requirements for establishing forage plants. Two tons of limestone, 50 pounds of nitrogen, and 44 pounds per acre of phosphorus were the only nutritional requirements for the establishment of a good stand of bahiagrass and Coastal bermudagrass on the clay pit spoil. These findings are particularly pertinent since no one has previously attempted to reclaim these problem areas. Further studies are planned to develop a procedure for rehabilitating large tracts of land by establishing useful plant covers. (SWC 10-b3)

Preliminary studies were made in 1966 at Beltsville, Maryland, to determine the amendments needed to revegetate the spoil left by coal strip mining in West Virginia. Results show that these spoils are extremely high in acid-producing material. By screening a large number of plants, a few were found that would persist under these unfavorable soil conditions. Field studies are planned to develop a soil and water system for revegetating these areas. (SWC 10-aB8)

#### B. Soil Chemical Properties

1. Soil acidity and plant growth. Differential aluminum tolerance studies of various crops reported in 1964 and 1965 have continued at Beltsville, Maryland. Results of studies using radioactive isotopes with two wheat varieties, the aluminum-sensitive Monon and the aluminum-tolerant Atlas, have shown that they differ in their ability to absorb calcium. In the absence of aluminum, Monon was more effective than Atlas in accumulating calcium in the plant tops. In the presence of aluminum, the situation was reversed. Studies of dry beans, snapbeans, and lima beans showed that varieties of these crops also differ widely in their tolerance to aluminum. These data are of great value to plant breeders concerned with developing varieties for acid soils ( SWC 10-aB8)

Studies were continued on defining the factors responsible for the shallow rooting of most crops in the Coastal Plains. In field studies at Florence, South Carolina, 77 to 88 percent of the roots were found in the Ap horizon. Laboratory studies showed that P was the limiting element in the soil horizons below the Ap. Future studies will be concerned with developing soil and water management systems to place the P deep in the soil profile. (SWC 10-b6)

At Auburn, Alabama, short-term growth chamber experiments have been conducted using soils collected from areas where cotton rooting is shallow. Results showed that very short-term measurements of cotton root elongation rate can successfully be used to predict yield response to subsoil acidity level. Cotton primary root penetration in Norfolk, Magnolia, and Greenville

subsoils in 48-hour growth chamber experiments reached maximum rate at subsoil pH values of 5.5 to 6.0. No consistent differences occurred among 5 commonly grown southeastern cotton varieties and one western variety. In field experiments on the same soils, yields dropped at subsoil pH levels that reduced primary root elongation rate by about 50 percent during 48 hours. Similar experiments with soybeans and peanuts revealed that soybean root elongation was less sensitive than cotton to subsoil acidity, and peanuts were very insensitive to subsoil pH in the range of 5.0 to 6.4. (SWC 10-b1)

To assess the influence of subsoil acidity on root growth, a series of plots have been developed at Thorsby, Alabama. Results indicated a close relationship between subsoil pH and depth of rooting, subsoil water utilization, rate of plant height increase, and final yield of seed cotton grown on a Greenville fine sand. Yields dropped sharply at subsoil pH levels below about 5.2. Plants on the plots with high subsoil acidity showed severe moisture stress. In a similar study at Monroeville, Alabama, on a Magnolia silt loam, subsoil pH levels below 5.1 were associated with a sharp decline in seed cotton yield and a clearcut reduction in root growth in the subsoil. These results, which are consistent with the yield response reported earlier for a Norfolk silt loam, indicate the importance of raising the subsoil pH. (SWC 10-b1)

At Auburn and Thorsby, Alabama, in studies concerned with developing a system for raising the subsoil pH, soil samples taken after 2 years of calcium nitrate surface applications show that the pH was raised an average of 0.6 in the 6- to 12-inch soil depths. However, no effect was apparent below 12 inches. These data suggest that a simple field method for raising the subsoil pH may require considerable effort. (SWC 10-b1)

Sugarcane yields in Puerto Rico have been of concern to the industry, researchers, and farmers for years. Results from a study initiated in 1966 to evaluate the response of sugarcane to lime indicate that low pH may be a major cause of the low production. Cane yields increased from less than 1 ton per acre when no lime was applied to a heavily fertilized cane as compared with over 40 tons when a total of 20 tons of limestone was applied per acre on the fertilized treatment. Exchangeable bases and aluminum proved to be good criteria for predicting the liming requirements. (SWC 10-b1)

2. Soil pesticide complex. During the year, pesticide research in the Division has dealt with understanding the basic principles of persistent chlorinated insecticide movement and transformation in soils. In an attempt to determine the movement of the chlorinated insecticides by leaching, columns of four soils were used at Fort Collins, Colorado. Water was added in depths of 5 and 10 inches to separate 10-cm.-diameter leaching columns. Movement of lindane was influenced by soil texture and amount of water applied. Considering movement of lindane as only that portion found in layers below

the 3-cm. depth, the movement was 5, 16, 59, and 47 percent of the total amount recovered for Promise clay, Raber silty clay, Hand loam, and Valentine laomy sand, respectively, after 10 inches of leaching. DDT remained in the 0- to 3-cm. layer in all soils regardless of the amount of water applied. Pesticide-amended soils subjected to wetting and drying cycles lost more lindane than DDT. In the treatments receiving 10 inches of water during the cycling process, 57 percent of the applied lindane was recovered compared with 76 percent of the DDT. (SWC 10-40 (d7))

One of the big concerns to agriculture today is the lack of a method for removing a persistent chlorinated hydrocarbon from a soil. In a study at Fort Collins, Colorado, DDT was completely converted to DDD after 6 months of anaerobic incubation. The rate of conversion was increased by amending the soil with 1 percent alfalfa. Under aerobic conditions, no decomposition occurred. To ascertain if dechlorination was a result of microbial conversion or catalytic conversion, a complete set of samples was sterilized for 1 hour in an autoclave. Results showed that no degradation occurred under either aerobic or anaerobic conditions when the soil was sterilized prior to incubation. These findings represent the first real breakthrough in finding methods for decontaminating soils polluted with chlorinated hydrocarbon insecticides. Future studies will involve the development of field systems to test the validity of these laboratory findings. (SWC 10-40 (d7))

In another study at Fort Collins concerned with determining the extent to which insecticides and their transformation products are adsorbed or react with soil organic constituents, results showed that the volatilization of lindane and DDT was greatly reduced in the presence of organic colloids as compared with a glass surface. Complete loss of lindane and DDT in glass vials occurred at temperatures of 60° C. and 80° C., respectively. In contrast, when the pesticides were added to organic colloids, a temperature of 150° C. was required to volatilize lindane and DDT. These data suggest that chlorinated hydrocarbons are strongly fixed by soil organic constituents. (SWC 10-40 (d7))

In another pesticide adsorption study at Fort Collins, the amount of DDT absorbed on Promise clay and Raber silty clay loam increased with length of incubation. Maximum adsorption was obtained after 28 days of incubation. Results suggest that the mechanisms of adsorption may be regulated by positive exchange sites on the reactive surface which form weak bonds with the electronegative chlorine atoms on the DDT molecule. (SWC 10-40 (d7))

Studies at Presque Isle, Maine, concerned with the amount of pesticides lost from potato fields in Aroostook County have shown that very little DDT, endrin, and Endosilfon are lost in runoff and erosion. The amount of pesticides lost from continuous potatoes was higher than that lost from potatoes in a rotation of potatoes, oats, and sod. (SWC 10-a1)

In a continuing study on the influence of clay minerals on the adsorption of simazine, atrazine, propazine, and prometryne, results showed that little or no adsorption occurred on kaolinite, considerable occurred on montmorillonite, and moderate amounts occurred on illite. Vermiculite was not nearly so adsorptive as expected from its permanent charge exchange acidity. In these same studies, heptachlor decomposed rapidly when mixed with the soil. (SWC 10-43(aB13))

During 1966, a season of below-average rainfall, the first data on the magnitude by which dieldrin was transported from agricultural lands into surface and subsurface waters was collected in a cooperative project between the North Appalachian Experimental Watershed, Coshocton, Ohio, and the U. S. Soils Laboratory at Beltsville. Analysis of the limited number of samples collected showed that considerable amounts of dieldrin were lost in the runoff from the treated areas. Major advances were made in developing procedures for sampling, storing, transporting, and analyzing soil and water samples. The project will be expanded during the coming year. (SWC 10-43(aB13))

During the year, work has continued on a PL-480 project in Spain concerned with obtaining physico-chemical information on the retention of pesticides on various clays as influenced by the soil moisture and temperature. Techniques have been developed for studying the diffusion of pesticides in water and other solvents. Results show that the diffusion of pesticides is dependent on clay properties. The surface area of the clay appears to be the important factor in determining pesticide behavior in soil. (E25-SWC-7)

3. Radioactive fallout. During the year, additional studies were undertaken to clarify basic principles important in minimizing the potential hazard of fission accumulation in soils and plants. Results showed that adsorption of some ions into slowly exchangeable or "occluded" forms in soils may greatly reduce their availability for uptake by plants. In soils from the Southeastern United States, 30 percent of the total Sr-90 may be "occluded." Experiments during the past year have shown that occlusion is a diffusion-controlled process closely associated with the organic fraction of the soils. The rate of equilibration of the occluded strontium depends upon the concentration and composition of the extracting solution. The "occlusion" effect is probably exhibited by calcium also. (AEC 0-0-1)

In new investigations at Beltsville concerned with the influence of the availability of moisture on strontium uptake, results show that at low moisture contents the strontium concentration increases in the soil solution while the calcium concentration remains constant, indicating the greatest strontium uptake from dry soils. These data are of value in predicting the strontium uptake by plants. (AEC 0-0-1)

Results of research conducted at Beltsville, Maryland, on decontamination of agricultural lands by physical means has shown that the uptake of buried strontium-85 by any crop can be reduced to a very low level if the depth of rooting is restricted. In order to determine if this treatment might be effective in lower rainfall areas, strontium-85 and sodium carbonate were applied to the surface of a Pullman silty clay loam and plowed to a depth of 30 inches at Bushland, Texas. The deep-plowed treatment was compared with a treatment where the strontium-85 was mixed with the surface soil with a rotary tiller. The concentration of strontium-85 in the plants growing on the sodium carbonate treatment was from 3 to 7 percent of that of plants grown on the rotary tilled plots. The sodium carbonate treatment had no effect on yield, but the deep plowing increased the yields of all of the crops studied. These data demonstrate that the uptake of buried radioactive materials by plants can be drastically reduced if a toxic chemical like sodium carbonate can be used to control the rooting depth. (AEC 0-0-1)

The radioactive elements contained in P ores have been of interest to scientists for sometime. At Beltsville, Maryland, the content of naturally occurring radionuclides was determined in an extensive worldwide collection of phosphate rocks. Phosphate rocks from Florida had the highest contents of radium, uranium, and thorium. However, the levels found were so low that application of fertilizers is not apt to lead to a significant increase in radionuclides in soils. (AEC 0-0-1)

#### C. Tillage, Residue Management, and Cropping Systems

1. Soil structure. The physical characteristics of soils, which determines how well a root will develop, are of primary concern in the effective utilization of the climatic environment. At Auburn, Alabama, the relation of bulk density and soil water to soil resistance to penetration has been established for three Coastal Plain soils. As well, the relation of soil resistance to penetration to cotton taproot penetration was shown to be highly linear, with a critical value of 310 p.s.i. above which no root penetration is expected. This value agrees well with critical values published for soils in other regions. (SWC 10-b6)

Studies at St. Paul, Minnesota, are concerned with bonding between clays and organic molecules and with the role of organic matter in stabilizing soil aggregates. Results of laboratory studies showed that variability in adsorption of polysaccharides on clays is probably due to differences in flocculation and dispersion of the clay preparations. When 5 percent of the polymer was added, surface adsorption was indicated. However, when 20 percent was added, both surface and inter-lamellar adsorption occurred. Soil crumbs synthesized from Peorian loess in combination with fungal treatment showed considerable resistance to osmotic stress and periodate oxidation. (SWC 10-c3)

A basic study, conducted at Adelaide, Australia, by one of the scientists on educational leave from Ames, Iowa, concerned the energy relationships required for soil breakup in a loam soil over a range in water contents. Results showed that soil breakup was more closely related to the strain energy than it was to the soil strength. Considerable effort was spent in developing a method for measuring axial strain and stress in a remolded loam soil under unconfined axial loading in both compression and tension over the water content range from air dry to 0.2 bar suction. The flexural strength of a soil was also measured over the water content range as a test of the accuracy of the rupture stress in tension. The strain energy required to rupture the loam soil in axial tension, taken as the area under the stress-strain curve, was shown to be relatively constant over a wide range of water contents. The results from this and other studies will be extremely useful in basic soil tillage design. (SWC 10-c3)

At Temple, Texas, evaluation of effects of soil profile modification on the structure of Houston Black clay continues. Initially, it was hypothesized that the increased porosity, reduced density, and increased water transmission rates resulting from soil loosening might be of short duration owing to slaking of the soil following wetting. After a 3-year period, however, the beneficial effects to structure by rototilling to a depth of 2 feet are still evident. The surface 6 to 8 inches has slaked until it is structurally similar to the undisturbed Houston Black clay. Below this zone, structure has changed very little and still exhibits the characteristic porous structure developed by the rototiller. The overall bulk volume increase is in excess of 20 percent. It is concluded that the soil will not slake to its original density for an indefinite period after deep rototilling if no compactive force other than precipitation is exerted on the soil. (SWC 10-e1)

2. Tillage. A new concept of mulch tillage for continuous spring wheat production was proposed and tested in 1966 at Mandan, North Dakota. Briefly, the concept proposed to bury weed seed with a conventional moldboard plow and at the same time to transfer clean straw onto the plowed surface from an adjacent unplowed strip of equivalent plow width. Data show that conventional mulching equipment (V-blade) failed to bury weed seeds--weeds were two to three times as numerous as with moldboard plowing, and wheat yields were reduced 13 percent. At wheat heading, N uptake by weeds on conventional mulch plots was more than double the uptake from any other tillage treatment. First-year results suggest that until more suitable herbicides become available the concept of plow-mulching is the most satisfactory method of providing protection against wind and water erosion. (SWC 10-d4)

At Bushland, Texas, the first year after plowing Pullman silty clay loam to depths of 8, 16, 24, and 32 inches, grain sorghum yields increased with plowing depth when irrigation was limited. With nearly adequate irrigation, yields were highest with the 16-inch plowing and decreased for shallower

or deeper depths. The three deeper plowing treatments markedly increased the quantity of water stored in the 6-foot profile. The increase in yields with plowing depth under less than optimum water supply can be attributed to increased soil moisture storage. (SWC 10-e1)

At eight locations in Alabama, tillage to a depth of 12 to 15 inches by a machine which planted directly over the chisel groove and applied pre-emergence herbicide in the same operation was evaluated as a means of improving the subsoil condition for rooting of cotton. Seed cotton yield was increased by 35 percent at Auburn and 53 percent at Tallassee and decreased by 14 and 21 percent at Sand Mountain and Normal, respectively. No effect was measured at the other locations. Root observations early in the growing season showed that the cotton taproots penetrated deeper and more rapidly in the chiseled rows at all locations. No explanation was given for the variable response; however, increased moisture is the suspected reason. (SWC 10-b6)

In an attempt to reduce the cost of raising potatoes at Presque Isle, Maine, conventional tillage has been compared with minimum tillage. Comparable yields were obtained with all systems studied. The most promising treatment was a once-over planting operation with a chisel-tooth cultivator mounted ahead of the planter. (SWC 10-a1)

At Marcellus, New York, where the grass was killed with herbicides and corn grown on the same plots for 3 years without tillage, yields the second and third years were not significantly different from yields under conventional tillage. Over a 3-year period, yields of corn at Blacksburg, Virginia, were the same on nontilled soil with a sod mulch as on conventional seedbeds with a heavy straw mulch, and averaged 25 percent higher than under conventional tillage. Both the straw and sod mulch greatly reduced runoff, lowered soil temperature, decreased evapotranspiration, and increased soil moisture. (SWC 10-a1)

After 3 years of study, the question of the value of deep plowing soils in the Palouse region has been resolved. Plowing 36 inches deep is beneficial on soils with a dense, impermeable subsoil or soil that has clay subsoil exposed by erosion. However, on a well-drained soil, deep plowing is not advantageous. On problem soils, the water stored in a 6-foot profile was increased 1.5 to 2.0 inches on the deep-plowed plots. The additional stored water was responsible for a 1-ton increase in alfalfa yields and for a 5- to 10-bushel increase in wheat yields. (SWC 10-f1)

At Bushland, Texas, moldboard plowing to a depth of 36 inches doubled yields of irrigated sugar beets and soybeans and gave 60 percent yield increases with cabbage and sudangrass. However, under full irrigation, deep plowing increased grain sorghum yields only by 17 percent, whereas under limited irrigation, yields were increased by 57 percent. These results

indicate not only that crops are differentially responsive to profile modification, but that the response of a given crop may depend on the moisture regime. (SWC 10-e2)

Cotton and sorghum yield increases from deep tillage of Houston Black clay at Temple, Texas, continue to be reported. During the 3 years the study has been underway, loosening the dense clay has resulted in increased root proliferation each year. Poor soil aeration is concluded to be the major factor affecting root development in these soils. To prevent reduced plant emergence in these soils, the seedbeds have to be well packed to assure good soil root contact. (SWC 10-e1)

3. Cropping systems. Most high-altitude native meadows in the Intermountain West annually produce about 1 ton of hay per acre. Meadow soils typically are covered with a tough sod mat due to high water tables and excessive irrigation. Moreover, many soils are very shallow. Usual methods of tilling, leveling, and reseeding are very difficult and expensive. Experiments at Gunnison, Colorado, have shown that production of these meadows can be increased as much as fivefold within 2 years by introducing improved grass and clovers, controlling irrigation, fertilizing, and harvesting at the right time. Improved forage species were introduced by removing 2- by 2-inch strips of sod and seeding in the resulting furrow. This system shows promise for quickly and economically restoring the productivity of this large forage-producing area. (SWC 10-d4)

Although the acreage of Coastal bermudagrass has more than doubled in the last decade, its value as a forage is still questioned. In a study at Watkinsville, Georgia, designed to provide insight into changes in chemical composition with maturity, results showed that changes in the chemical composition of the cell walls with maturity were minor, but in vitro digestibility decreased substantially by all criteria with later harvest. Profile sampling in the sward revealed that the quality declined from the top to the bottom of the plant. These data indicate that the highest quality Coastal bermudagrass forage is obtained when stands are cut well before maturity, leaving a high stubble (SWC 10-b3)

In an attempt to develop systems for increasing the food production in the Latin American countries, cropping systems for maximum production of plantains and yams have been studied in Puerto Rico. By increasing the plant population of plantains from 600 plants per acre to 1450 per acre and changing the planting pattern, the yield was increased from 8 tons to 13 tons per acre. These population and planting pattern changes did not significantly affect size of fruit or bunch, but primarily increased the number of trees bearing a crop. Yams planted in beds and staked yielded 26 tons per acre at high population as compared with 19 tons in the currently used 4-foot rows. These observed yield increases of two major food crops of the humid tropics obtained by merely modifying plant population and planting patterns emphasizes the tremendous potential of this environment for food production. (SWC 10-b5)

Corn Belt farmers are faced with necessity to produce more efficiently in order to compete with other land resource areas. In studies conducted over a 3-year period on Sharon silt loam under irrigation at Elsberry, Missouri, to determine the factors limiting corn production, yields of 160 bushels per acre were produced on treatments that had 20,000 plants per acre in a 30-inch row spacing. High application of N, P, and K were required for maximum yields. (SWC 10-cl)

Daily weight gains of steers were increased and carcass grade improved at Watkinsville, Georgia, by using well-fertilized Coastal bermudagrass as a pasture and feeding 3 pounds of crushed ear corn daily per animal as compared with Coastal bermudagrass alone. Steers fed a forage produced from sod gained as much or more than steers fed a forage produced from row crops. (SWC 10-b7)

#### D. Soil Microbiology

1. Inoculation of legumes. Yields of soybeans could be increased if plants could be nodulated with rhizobial strains of high N-fixing potential. Field and laboratory studies at Beltsville, Maryland, have consistently shown that plants inoculated with R. japonicum by conventional methods will only have a small percentage of nodules produced from the introduced population. Detailed studies conducted during the past season showed the nodulations on most well-inoculated plantings were almost all produced by indigenous soil strains. Strains of introduced bacteria differed in their ability to survive competitively in the soil. Future studies will be concerned with developing field methods for inoculating soybeans with effective bacteria. (SWC 10-36{a3})

During the year, the studies on "sick alfalfa" have continued at Prosser, Washington. Rhizobium bacteria survival problems were essentially eliminated in a problem soil by incorporating 4 tons  $\text{CaCO}_3$  per acre. Very little microbial antagonism was found in problem soils, but nodulation rate was low. Liming increased the nodulation rate. A bacteria virus (phage) was found in several problem soils, but the phage did not seem to be an important factor limiting bacteria survival. Soil titration studies indicate that a good population of effective Rhizobium bacteria is present in "sick alfalfa" fields where inoculation has been carried out. (SWC 10-f4)

2. Volatile substances from alfalfa. Last year it was reported that volatile substances given off by alfalfa or other plant residues induced a striking increase in the respiration rate of soils exposed to them. In further studies, a standard assay test was developed using preincubated Drummer soil in the Warburg respirometers. From this it was found that the active substance reaches a saturation level in water. This maximum response in the assay test is on the order of  $7.5 \mu\text{l}$  oxygen/hr/g soil, approximately 10 times higher than that of the control. The volatility

of the substance is not affected by pH, indicating that it is a neutral organic compound. RQ values for the respiration response indicate that the respiratory substrates involved are either fats or proteins. Repeated exposure of the same soil samples at 2-week intervals induces a progressively greater response in respiration rate. Vapor over a saturated solution of the alfalfa volatiles was lethal to soil micro-organisms exposed on agar discs. Sensitivity among fungi varies, but spore germination is completely inhibited by concentrations as low as 0.4 percent of saturation. Respirometer tests showed that a pronounced increase in spore respiration occurs without germination. The present data indicate that the volatile substance induces a striking increase in respiration rate that is associated with rapid death of organisms at high concentration but may stimulate growth at lower concentrations. Ecological changes in soils as a result of this stimulation, particularly the fate of dormant plant pathogens, are now being investigated. (SWC 10-aB)

3. Decomposition of residues. In several previous studies conducted in the laboratory and greenhouse at Lincoln, Nebraska, results showed that patulin, a phytotoxin substance produced by the fungi, Penicillium urticae Bainier, is toxic to many crops. Results from recent studies show that patulin added to wheat in the greenhouse reduced germination and produced symptoms similar to those observed on plants in the field on stubble-mulched treatments. Patulin-treated plants were more susceptible to smut and mildew diseases. During the year, patulin was added to field plots at North Platte. Field observations showed that wheat emergence on patulin-treated plots was delayed. (SWC 10-d5)

Water extract of tops and roots of crops and weeds have been applied to the important cash crops at Florence, South Carolina. Results showed that extracts from certain crops are toxic to specific crops. For example, dogfennel and cotton extracts inhibited germination and emergence of corn only, and ragweed and soybean extracts severely inhibited the emergence of oats only. Root extracts had a lesser effect than top extracts. These studies have some significant implications in the managing of crop residues and in the sequence of cropping for efficient production. (SWC 10-b5)

4. Role of micro-organisms in reclamation. In an attempt to reclaim vast areas of alkaline lands in India, a PL-480 project has been initiated to determine the role of micro-organisms in reclamation. The first study has involved isolating micro-organisms from alkaline and fertile soils. To date, progress has been made in cataloging the fungus found in these soils. Future studies will be concerned with studying the ecological specialization of these organisms. (A7-SWC-33)

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AREA 11: SOIL, WATER, AND PLANT RELATIONS AS THEY  
AFFECT USE OF LAND AND WATER RESOURCES

Problem. Most of the water used in agriculture is returned to the atmosphere by the process of root absorption and leaf transpiration. Our understanding of the physical, physiological, and phenological aspects of the extraction of water from soil by roots, its translocation upward, and the manner in which water is lost from the leaves is limited. The productiveness of the soil depends to a large degree on how water moves within the soil. The mechanisms involved in the movement of water in the soil and to the plant root have not been adequately explained; consequently, the behavior of water in soil cannot be satisfactorily predicted. No basic understanding of naturally occurring field phenomena can be reached until our knowledge of water movement through soils and to plant roots is expanded.

The immediate climatic environment around the plant and at the soil surface, and the micrometeorological factors that affect these, have a profound influence on the growth of the plant, the loss of moisture from the soil and plant, and on the soil itself. These micrometeorological factors offer a means of conserving moisture during plant development. It has been estimated that 80 percent of the sun's energy is used each year to evaporate some 2 million acre-feet of water from plants and soil. The total energy cannot be altered, but it should be possible to divert a greater percentage to use for photosynthesis rather than for evaporation.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves soil physicists, soil chemists, plant physiologists, and engineers in both basic and applied studies. The Division scientific effort devoted to this research totals 21.69 professional man-years. Of this number, 10.09 are devoted to soil physical properties as related to movement of air and water into plant roots; 6.30 to determination of plant-soil-meteorological interactions; and 5.30 to development of soil and crop management factors for maximum energy conversion.

PROGRAM OF STATE EXPERIMENT STATIONS

A total of 48 scientific man-years is devoted to this research.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Soil Physical Properties as Related to the Movement of Air and Water Into Plant Roots

1. Interaction of matric and osmotic suction. Any progress made in understanding the mechanisms of water binding in the soil is dependent upon sound theory and good experimental procedures. Of primary importance is an understanding of the interactions of matric and osmotic components on the total water potential under varied soil solution composition and concentration and on different soil types.

A study was undertaken at the U.S. Salinity Laboratory, Riverside, California, to determine if the interactions of the matric and osmotic components were significant or if the two were additive. Results from an experiment with a  $\text{Ca}^{++}$  saturated Vale soil showed that the sum of matric and osmotic components was the same as the measured total water potential. From these data, it would appear that the pressure dependence and/or interaction of the two components are insignificant and that the two components can be summed. In addition to collecting data on the mechanisms of water binding, the procedure developed to collect the data offers the first possibility of direct measurement of both matric and osmotic potential on a soil sample removed from the field. (SWC 11-gF1)

2. Measuring moisture stress. The availability of soil water to plants, moisture stress in plants, and leaf water vapor pressure can best be described by the concept of relative activity. Instruments developed to date to determine this fundamental and well-proven concept have not been satisfactory. During the year, the precision of the Peltier thermocouple psychrometer was improved by the construction of an inexpensive thermostat. Data collected with this thermostat indicate that absolute temperature control in the system is not critical, but the rate of change in temperature is. Future studies will be confined to adapting this instrument to plant and soil-water systems. (SWC 11-b2)

3. Vertical infiltration. A theoretical study at Urbana, Illinois, may explain the puzzling field observation that gullies often widen due to slumping of soil on the bank above the bottom of the gully. In a theoretical study the hillside adjacent to the gully is visualized as a sloping slab of soil, with the lower face of the slab the gully wall. Numerical analysis of unsaturated water flow in the sloping slab of soil indicates that under some conditions, water outflow across the downhill end of the slab reaches a peak rate at some point above the bottom of the slab. This suggests that because of high water contents soil strength is low along the lower gully bank. Overburden pressures and forces of running water may then exceed the strength of the soil and thereby cause bank erosion. (SWC 11-cl)

In a study at Urbana, Illinois, designed to study the hydraulic conductivity in the laboratory under simulated field conditions, results continue to show that the solution to the flow equation with a source term can be obtained by a numerical means. The theoretical influence of the parameters in the source term model on the flow of water in the soil was described. In observing the flow of water from a wet soil to drier soils by plant roots, the downward flow of water in the profile was predicted. The source term model used in this study was not the ultimate in describing the uptake of water by the root. However, it was a reasonable first attempt which awaits further experimental investigations. (SWC 11-c3)

Results from studies to relate infiltrometer data collected in the laboratory at Ames, Iowa, to actual field rates have shown that soil surface conditions must be considered. Infiltration estimated from laboratory data and a numerical solution of the water flow equation was consistently less when the effect of a surface seal was considered than when no seal was present. When no seal was present, cumulative infiltration after 2 hours at six sites ranged from 2.7 to 4.9 cm. when the soil was initially at 20 percent water content (dry antecedent conditions) and 2.1 to 4.5 cm. when the initial water content was near field capacity (wet antecedent conditions). When the effect of the developing surface seal was considered, the estimated 2-hour accumulation into the same six profiles ranged from 2.2 to 4.2 cm. (dry) and 1.9 to 4.1 cm. (wet). (SWC 10-c2)

4. Influence of water table. The question of how much water crops can get from a shallow water table has been asked repeatedly by farmer and action agency personnel. Results from a 4-year lysimeter study at Weslaco, Texas, designed to determine the contribution of a water table to the water requirements of cotton show that cotton can extract water from a 9-foot water table. Half of the treatments were irrigated when 90 percent of the available water had been extracted and the other half was irrigated when 50 percent had been used. Total moisture use averaged 29 inches under both moisture regimes for the 4-year period. The 4-year mean percentages of total water use attributable to use from the three water table depths (3, 6, and 9 feet, respectively) have been 54, 26, and 17 percent for the high moisture level, and 61, 49, and 39 percent for the low moisture level treatment. (SWC 11-e1)

5. Soil aeration. In a laboratory study at Grand Junction, Colorado, germination and root elongation of corn in silty clay loam at low soil water suctions were controlled primarily by changes of  $O_2$  diffusivity and resultant changes of  $O_2$  concentrations. Redox potentials were in accord. Measured  $O_2$  concentrations agreed with values predicted by diffusion theory. Aggregate size, air porosity, and bulk density (over the range used) influenced root elongation only to the extent that they influenced  $O_2$  diffusivity. Root elongation rates tended to decline at soil water suctions greater than needed for adequate soil aeration. (SWC 11-d1)

Farmers and ranchers in the Northwest have observed "June Yellows" in their alfalfa for the past decade. Although the condition occurs frequently after a heavy irrigation in the early summer, it had never been induced in the greenhouse. During the year "June Yellows" was observed for the first time in the greenhouse at Twin Falls, Idaho, in a wet soil with a low oxygen level. Laboratory, greenhouse, and field studies are continuing in an effort to determine if the condition can be corrected by oxygen enrichment. (SWC 10-f2)

## B. Determination of Plant-Soil-Meteorological Interactions

1. Radiant energy. The increased demands for soybean products have had a favorable influence on the soybean market which has been reflected in an increased soybean acreage. This increased activity has created a demand for a better understanding of soil and water conditions associated with soybean production. At Urbana, Illinois, net radiation, apparent photosynthesis, and evapotranspiration were measured on three isogenic strains of soybeans (normal, narrow leaf, and dwarf). Results showed a direct correlation between total incoming solar radiation, apparent photosynthesis, and evapotranspiration on days with relatively low to medium incoming radiation. However, when incoming radiation was noticeably greater, there was a considerable decrease in the apparent photosynthesis. Several times during the season there was a significant increase in apparent photosynthesis in response to irrigation even though the plants showed no evidence of water stress. No measurable difference in apparent photosynthesis was observed between soybean strains. These data indicate that apparent photosynthesis in soybeans is much more responsive to soil water than to light. (SWC 11-c2)

Spectral characteristics of plant leaves as influenced by drying and freezing have been studied at Urbana, Illinois, so that data from remote sensing (e.g., high altitude photography) can better be interpreted. All leaves tested increased in reflectance of visible light as they dried. The actual color (or the shape of the reflectance curve in either the visible or infrared) of soybean leaves changes very little with drying, but cotton leaves usually develop a marked reddish color. The reflectance of corn leaves at longer wavelength than 350  $\mu$  was greatly increased by drying. Freezing of a cotton leaf caused no change in the visible reflectance, but infrared reflectance increased from 800 to 1300  $\mu$ . The reflectance spectrum of a frozen leaf from 1300  $\mu$  to 2500  $\mu$  shows a curve characteristic of ice crystals, rather than the normal water curve shown by a fresh leaf. As a cotton leaf is thawed, the reflectance drops drastically because the cell integrity within the leaf has been violated and water leaks into the intercellular spaces. (SWC 11-c1)

In field experiments using closed plastic chamber systems at State College, Mississippi, okra-leaved Rex cotton intercepted considerably more

light than normal-leafed Rex cotton at comparable leaf indices. This was due to the interception of light by plant parts other than leaves. Under high radiation loads, the okra-leafed cotton transpired less water than the normal cotton. Okra-leafed plants may offset the larger stresses by partial stomatal closure. (SWC 11-b1)

Several investigators have recently reported that a plant growth regulator known as 2,3,5-triiodobenzoic acid (TIBA) produces favorable morphological changes in plants. Light interception was increased in Lee soybeans by a foliar spray treatment with TIBA at State College, Mississippi. Total number of pods per plant was increased, while weight per seed was slightly reduced. Small soybean yield increases were measured on most TIBA treatments. Further studies are planned to find out if TIBA can increase the plants' use of energy, water, and essential elements. (SWC 11-b1)

The ability to calculate transpiration from appropriate plant and environment measurements would enhance our understanding of the complex process of plant water loss and might lead ultimately to the resolution of evapotranspiration into its components of evaporation and transpiration. In an attempt to obtain reliable data for the transpiration equation, the transpiration of cotton, sunflower, lemon, and bean plants was studied at Phoenix, Arizona, in a controlled environment chamber under conditions of virtual darkness and high illumination, up to 60 kilolux. Knowledge of leaf temperature, leaf diffusion resistance, ambient vapor density, and boundary layer resistance permitted calculation of transpiration for individual leaves. Agreement between calculated transpiration and that measured gravimetrically ranged from poor for lemon, where some weighing error may be involved, to good for cotton with only 10 percent error. On the whole, calculated transpiration was within 20 percent of the reference value. The overall agreement is believed sufficient to have verified the transpiration equation. (SWC 11-gG1)

2. Stomatal activity. In a study of the relation of temperature and moisture level to the evapotranspiration rate of cotton plants at Weslaco, Texas, stomatal activity was measured for several treatments. Measurements made on leaves arising from different nodes down from the terminal of cotton plants showed that both stomate length and stomate numbers per unit area varied with leaf size. Leaf size varied with moisture stress. Young, expanding leaves had more stomates per square centimeter than large non-stressed leaves or intermediate size stressed leaves. Stomate apertures indicated that a moisture stress gradient exists down the stalk of weakly stressed plants but that the stress was uniform for at least seven nodes down the plant under greater stress conditions. These distributions of stomate concentrations and sizes may have important implications in leaf selection to characterize the diffusion resistance of leaves, plants, and plant canopies. (SWC 11-e1)

Additional studies at Ithaca, New York, involved the measurement and interpretation of water stress in leaves, and its overall relation to the photosynthetic process. Under ample soil water, stomatal behavior is primarily dependent upon light, but soybeans have a more favorable water-conserving system than sunflowers, and corn even better than soybeans. Using two new experimental techniques, results show that the leaf to air transfer of heat and water vapor through the leaf boundary layer was much greater than predicted by conventional engineering heat transfer equations. This may be due in part to turbulence found in plant canopies and the proximity of leaves and stems to each other. If this is correct, present models of plant canopy response (photosynthesis and transpiration) based upon integration of individual leaves without considering the interaction of leaves may be seriously in error. Development of a correct model will greatly aid our understanding of these physiological processes. (SWC 11-a1)

Studies have continued at Watkinsville, Georgia, in a search for an economic method for controlling the movement of guard cells. A study of the mechanism of guard cell action has indicated that an accumulation process for cations is associated with stomatal opening and that a pair of guard cells is really one cell. An enzyme showing phosphorylase activity has been extracted from the epidermis of Vicia faba, probably originating in guard cells. Future studies will be confined to determining whether or not the enzyme phosphorylase is operative. (SWC 11-b2)

At Urbana, Illinois, research is underway to determine how transpiration by leaves might be reduced through applications of plastic coatings over the leaf including stomatal apertures. Such coatings would have to be more permeable to carbon dioxide than to water so that the plant could maintain a high photosynthetic rate and yet not lose a great deal of water. The permeability of ten types of plastic films to water and to carbon dioxide was measured. No material was found to have a carbon dioxide permeability as great as its water permeability. Thus, none of the materials tested appears to have the desired characteristics. Tests to determine the permeability to water and carbon dioxide of other materials are being continued. (SWC 11-c1)

3. Diurnal growth of plants. Leaf measurements made on grain sorghum at Bushland, Texas, reported in 1965, showed that growth was not continuous as has been commonly reported in plant physiology textbooks. During the year, measurements have been made with wheat and corn. Results show that the most rapid growth occurs in the afternoon and the slowest growth between sunrise and 8:00 a.m. Only when severely moisture stressed, did corn and sorghum make more growth at night than during the day. These measurements also revealed many characteristics of the daily growth patterns. In sorghum, the growth rate is maximal near sundown and greater during the day under cumulus cloud shade than under full sunshine.

Spraying the leaves with water or 5-percent urea solution had no apparent effect on growth rate. At night, condensation of dew and small increases in either temperature or humidity cause an increase in the growth rate of wheat, corn, and sorghum. (SWC 11-e1)

Progress in the understanding of plant-water relationships has been retarded because of inadequate procedures. During the past year, a new system has been developed at Watkinsville, Georgia, for conducting plant-water research for plants growing in nutrient solution under a controlled environment. The system is capable of continuous measurement of the total green weight of a plant and of the absorption rate of solution by the roots. The system is primarily useful for intensive studies of time-dependent responses of a single plant. (SWC 11-b2)

4. Soil temperature. In the Appalachian region, information is badly needed on the influence of slope inclination and orientation on the species adaptation of the major forage crops. Pasture soil studies on northern vs. southern exposures at Morgantown, West Virginia, showed marked differences in soil temperature, plant growth, and responses to nitrogen fertilizer. On clear days, maximum soil temperatures 1 inch below the soil surface on new seedings were as much as 30° to 40° F. higher on southern than on northern exposures. Well-established, heavily fertilized Kentucky bluegrass on a northern exposure produced about five times as much forage as plots on a southern exposure. The plots on the two exposures were on 30 to 35 percent slopes on the same soil type, less than 100 yards apart. Data from these studies suggest that the warm season species should be used on southern slopes and cool season species on northern slopes if maximum forage production is to be realized in the Appalachian region. (SWC 10-a2)

Studies at Morris, Minnesota, showed that spring soil temperatures increased more rapidly under fall plowing than under spring plowing, the soil temperature being 3° F. higher at planting time. Soil temperatures in the fall-plowed treatment were still significantly higher on July 15 than from spring-plowed treatments, and this apparently resulted in a threefold difference in early season corn growth. Previous studies at Morris, Minnesota, and at Ames, Iowa, have also shown the importance of spring soil temperatures upon the growth of corn. (SWC 10-c2)

#### C. Development of Soil and Crop Management Factors for Maximum Energy Conversion

1. The energy budget at the earth's surface. The interactions of soil, plant, and micrometeorology greatly influence the food production potential of a given crop. Considerably more research has been conducted on soil-plant interactions than has been conducted on soil-microclimate and plant-microclimate interactions. Current research in the Northeast is designed

to measure and evaluate these interactions in order to furnish guidelines for developing management practices to maximize food production from the resources available.

As part of the overall microclimatology project at Ithaca, New York, simultaneous energy balance and momentum balance studies were made in three crops--sunflowers, soybeans, and lupines. Results indicate that measurement of the frequency distribution of light intensity classes at various levels in these crops is more meaningful to the nonlinear response of leaf photosynthesis to light. In corn, all of the corn plant leaves, regardless of their position in the canopy, responded to light in the same way at a given time of day. Another factor related to photosynthetic efficiency is CO<sub>2</sub> distribution in and above the crop canopy. Studies of wind profiles in a corn field indicated that large-scale eddies move across a corn field at a much slower rate than mean windspeed and thereby affect the CO<sub>2</sub> distribution within the canopy. It was also indicated that this eddy structure, and probably CO<sub>2</sub> fluctuations in the air stream could be affected by topographic features of the landscape. The momentum balance in corn has proved successful in estimating CO<sub>2</sub> exchange distribution in the crop canopy. These factors are significant in achieving a better understanding of photosynthetic efficiency under field conditions.  
(SWC 11-a1)

2. Influence of barriers on microclimate. At Morris, Minnesota, soybean yield increases were obtained for the fourth straight year in areas sheltered by windbreaks composed of corn rows. Hail damage was severe in 1966, and most other plant characteristics were not significantly influenced by the windbreak treatment at the time of measurement. Because windbreaks are most effective when placed perpendicular to the prevailing winds, two systems were designed and tested for obtaining quantitative data on wind direction and speed. It was found that 35 percent of the total wind travel during the growing season came from the south compared with 16 percent from the north, 22 percent from the east, and 27 percent from the west. A promising instrument also was developed and tested in 1966 for determining the Bowen ratio. The instrument utilized semiconductor diodes as the wet-bulk and dry-bulk temperature sensors. (SWC 11-c2)

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

Soil Physical Properties as Related to the Movement of Air and Water  
Into Plant Roots

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AREA 12: NUTRITION OF ANIMALS AS AFFECTED BY PROPERTIES  
AND CHARACTERISTICS OF SOILS AND PLANTS

Problem. To improve nutrition of animals and man by discovering relationships among soils, plants, and animals; to develop basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; to determine the functions and pathways of transport of the various elements throughout the food chain from soil to plant to animal; to identify and characterize soil and climatic areas where the nutritional status of animals and man is affected by qualities of the plants produced; to determine the relationships among soil properties, both natural and as modified by treatment, climatic factors, and the nutritional quality of plants as measured chemically or by feeding test animals, so as to maintain and improve the nutritional quality of human and animal diets.

USDA AND COOPERATIVE PROGRAM

This research is centered at the Department's U. S. Plant, Soil, and Nutrition Laboratory, located on the campus of Cornell University. Problems in animal nutrition that are prevalent in specific regions are investigated through field surveys in which the incidence of the nutritional problem is related to the composition of forages, types of soil, and other environmental factors. The chemistry of micronutrients in soils is under intensive study in order to develop basic knowledge of factors that influence the micronutrient content of plants. Other investigations are directed toward understanding the functioning of micronutrients in the animal, and the mechanisms involved in the interactions between micronutrients in animal nutrition. Studies of the site and mechanism of absorption of trace elements in the gastrointestinal tract are underway. The processes involved in the synthesis and breakdown of nutritionally important compounds in plants and animals are under investigation. One phase of these studies is directed toward the mechanism of formation and metabolism of amino acids and related compounds in plants, with special attention being directed toward the sulfur-containing amino acids. Another phase of this work is concerned with the mechanisms whereby amino acids are linked together to form protein, and the relationship between molecular structure and the biological function of some of the compounds that play important roles in protein synthesis.

Studies involving large animals are conducted through cooperation with state agricultural experiment stations. Studies of plant composition in relation to the occurrence of "grass tetany" in cattle are underway in cooperation with the Georgia, Nevada, and California State Experiment Stations.

The Federal scientific effort devoted to research in this area totals 14 professional man-years. Of this number, 4 are working on the effect of soils upon the nutritional quality of plants; 1 on mapping soil areas that produce plants containing levels of trace elements that result in deficiencies or toxicities to animals; 1 the chemistry of micronutrients in soils; 4 the biosynthesis of amino acids and proteins; and 4 on trace element functions and interactions in animal nutrition. The Soil Conservation Service maintains a full-time scientist at the Plant, Soil, and Nutrition Laboratory for studies relating nutritional problems to specific kinds of soil.

#### PROGRAM OF STATE EXPERIMENT STATIONS

A total of 12\* scientific man-years is devoted to this research.

#### PROGRESS -- USDA AND COOPERATIVE PROGRAMS

##### A. The Effect of Soils Upon the Nutritional Quality of Plants

1. Soil and plant factors related to the occurrence of "grass tetany" in cattle. Grass tetany is a frequently fatal disorder which strikes lactating cows when they are pastured on the new growth of cool-season grasses or winter cereals. In 1965, workers at the California Agricultural Experiment Station found high concentrations of trans-aconitic acid in certain grasses coincident with the most frequent occurrences of grass tetany in cattle. An experiment involving three-way cooperation between the Nevada Agricultural Experiment Station, the U. S. Plant, Soil, and Nutrition Laboratory, and the California Agricultural Experiment Station has been conducted to determine the role of trans-aconitic acid in grass tetany. Since trans-aconitic acid is derived from citric acid in plants, the possible implication of citric acid in grass tetany was also investigated in the same series of experiments. When heavy doses of either trans-aconitic acid or citric acid, plus KCl, were placed in the rumen, many of the cows developed the classic symptoms of grass tetany within 30 minutes. Prompt treatment with an intravenous injection of Mg-Ca gluconate (the conventional treatment for grass tetany) was required to prevent death. This was the first instance where grass tetany in cattle has been produced under controlled experimental conditions. Studies of the role of the added KCl, the effects of KCl plus trans-aconitic or citric acid on blood Mg levels, and the effects of Mg supplementation of the animal are now underway.

Since grass tetany is predominately a problem of cool seasons, the effects of temperature upon the concentration of Mg and other constituents in grasses that may affect the incidence of grass tetany are being studied

\*Also reported in Animal Husbandry

of it becomes available to plants during the first 6 months after addition. On neutral soils (pH 7.0), added elemental Se is slowly converted to forms that are available to the plant. In all the soils used in this work, increasing the pH of the soil from slightly acid (5.5 to 6.0) to neutral (7.0 to 7.5) increases the availability to plants of all forms of Se. The direct addition of a soluble selenite to the soil may be almost as useful for the production of crops containing protective but nontoxic levels of Se.

A study of the accumulation of Se by different plant species, growing on a soil containing a relatively low amount of available Se, has been completed. The results show that if the addition of Se to the soil does become a practical technique for the prevention of Se deficiency in livestock, it is unlikely that any plant species that might be planted on Se-treated soils, or any weeds that might invade Se-treated fields, will accumulate dangerously high levels of this element. (SWC 12-aA2)

B. Mapping of Soil Areas that Produce Plants Containing Levels of Trace Elements that Result in Deficiencies or Toxicities to Animals

1. Selenium in forages and grains in the United States. A map showing the generalized distribution of Se in forages and grains has been prepared in cooperation with the Soil Conservation Service and the Northwest Branch of this Division. In the Pacific Northwest and part of northern California, forages and grains are very low in Se. Another area producing plants of very low Se concentration occupies the lower Coastal Plain and Tidewater regions of the Southeastern Seaboard States and most of Florida. Areas where plants are generally low in Se, include the eastern part of the Corn Belt, plus Pennsylvania, New York, and the New England States. A very large contiguous area in the West-central United States, including the Great Plains, the western Corn Belt, the lower Mississippi Valley, and Gulf Coastal Plain produces cereals and forages containing adequate levels of Se. Plants containing potentially toxic levels of Se may be found in a few localized places in this area. The remainder of the United States was classified as producing plants of variable Se concentration, with samples containing adequate levels of Se occurring intermingled with samples containing very low levels of Se. With further work on a state-by-state basis, it may become possible to subdivide the areas now classified as variable into smaller areas characterized by adequate or low Se plants. This map alerts stockmen and veterinarians to the possibility of Se deficiency in the areas where plants contain low and very low amounts of Se. (SWC 12-aA1)

White muscle disease of lambs and turkeys is being studied in a Pl-480 project in Turkey. Preliminary results show that this disease is a problem in a large section of the country and that the incidence differs with years. Research results have been put into use by practicing veterinarians on sheep and goats in Turkey. (A22-AH-2)

at Ithaca. In these experiments, perennial ryegrass has been grown at two temperature regimes (57° F., night, and 68° F., day; versus 74° F., night, and 79° F., day) in sand cultures with nutrient solutions. The ryegrass contained more sugars and lower concentrations of Mg and Ca at the lower temperatures. It appears possible, therefore, that the low Mg contents in grasses, plus some changes in metabolism affecting the sugar-citric acid-trans-aconitic acid levels, found in plants during cool seasons, are compounding factors affecting the incidence of grass tetany.

A field study of the composition of crested wheatgrass in relation to weather conditions during the early growing season is underway in cooperation with the Northwest, Northern Plains, and Southwest Branches of the Division. In this study, the relation of temperature and rainfall to the concentration of magnesium, potassium, trans-aconitic acid and other constituents that may be related to grass tetany will be determined in crested wheatgrass growing under range conditions.

Experiments conducted in cooperation with the Georgia Coastal Plain Experiment Station at Tifton, Georgia, are directed toward determining the effect of the level of available Mg in the soil where the forages are grown upon the incidence of grass tetany. The Mg concentration in the forage was increased and the K and Ca levels decreased by Mg fertilization. The levels of trans-aconitic acid in the forage were not affected by the use of Mg fertilizer. Levels of Mg in the blood and urine of cows fed forage from the untreated part of the field showed an initial drop to levels substantially below those of cows fed forage from the treated part of the field. After a few weeks, however, this difference in Mg levels tended to disappear. At no time did the serum Mg concentrations drop to levels ordinarily found in cattle with grass tetany. (SWC 12-aA2)

2. Selenium in the soil-plant-animal cycle. The objectives of the past 6 years of research on selenium at the U. S. Plant, Soil, and Nutrition Laboratory have been to develop an understanding of the pathways of movement of Se in the soil-plant-animal cycle, and to investigate ways of controlling this cycle to improve the efficiency of livestock production. Earlier studies had shown that it might be possible to protect animals from Se deficiency by adding Se to the soils used for feed crop production. Since excessive levels of Se in feeds are toxic to animals, and there are soils that naturally produce feeds containing toxic levels of Se, a thorough understanding of the chemistry of Se in soils is essential to any evaluation of the practical use of this technique.

During the past year, different forms of Se have been added to various soils in order to determine their stability and their availability to plants. Soluble selenites are fixed by soils in forms that have relatively low solubility and relatively low availability to plants. When elemental Se is added to acid (pH < 6.0) soils, it appears to be inert and very little

2. Areas in Oregon that may produce forages containing toxic levels of molybdenum. Reports of molybdenosis (Mo-induced copper deficiency) in grazing cattle in parts of Oregon have been noted for some time. A survey designed to delineate the areas where forages may contain potentially toxic concentrations of Mo has been completed in cooperation with the Soil Conservation Service and the Oregon Agricultural Experiment Station. Three areas that produce forages high in Mo were located. In each of these areas, the plants with high concentrations of Mo are found on alluvial soils on the floodplains of small streams. (SWC 12-aA1)

3. Geographic variations in the levels of trace elements in normal human blood in the United States. A study of trace element levels in human blood is underway at the U. S. Plant, Soil, and Nutrition Laboratory to determine whether regional variations in the trace element levels in plants are a potential factor affecting the quality of human diets in different parts of the United States. The "pilot tubes" used for blood were supplied through the courtesy of a number of blood banks. At least ten individual samples of blood have been obtained from fifteen different locations in the United States. Techniques have been developed for measuring the concentration of five different trace elements in these small (about 8 ml.) blood samples. From preliminary results, it appears that there is relatively little variation in the Se content of blood from residents of different parts of the United States. Molybdenum and cadmium levels in blood show a somewhat greater geographic variation. The extent to which the local food supply, water supply, or air pollutants are related to the variations in Mo and Cd concentrations in blood is unknown at present. (SWC 12-aA1)

#### C. The Chemistry of Micronutrients in Soils

1. Complexing of metal ions in soil solutions and its effect upon the availability of micronutrients to plants. In many soils, the metallic cations in the soil solution are present in complexed or nonionic forms. In a continuing study of the complexing of trace metals, some of the constituents of a soil solution responsible for complexing Cu and Zn have been separated and partially characterized. Three groups of materials have been distinguished. Simple fatty acids, common amino acids, and a high molecular weight material were found to complex Cu and Zn.

The availability to corn of complexed and ionic Cu was compared in a culture solution experiment. The results of the experiment indicated that Cu is exchanged between the complexing agent and the root. Corn absorbed up to 80 percent as much Cu from the complexed Cu treatment as from Cu sulfate.

A mathematical model has been developed to describe the contribution of complexing agents to the transport of metal ions to roots. Among the

concepts that became evident from this model is that ions competing for the complexing agent may be important in enhancing the ability of the root to remove desired metals from their complexes. This effect, together with the fact that high concentrations of competing ions may completely displace metals of interest from their complexes, gives rise to an optimum range of competing ions to give the most desired effect. The optimum concentration of competing ions and its maximum effect can be calculated from the model in terms of measurable parameters. (SWC 12-aA5)

#### D. Biosynthesis of Amino Acids and Proteins

1. The structure of the transfer ribonucleic acids. The nucleotide sequence of a ribonucleic acid which transfers the amino acid tyrosine to the site of protein synthesis in living cells has been completely determined. Resolution of a few short segments of the long-chain molecule, where the exact order of nucleotides was in doubt a year ago, revealed that there is only one transfer ribonucleic acid for tyrosine in baker's yeast. Earlier indications that two transfer amino acids for tyrosine were present in baker's yeast were found to be due to the fact that one of the terminal nucleotides was missing from part of the tyrosine transfer ribonucleic acid.

An investigation of the amino acid-transferring ribonucleic acids from some food crops (peas and corn) has been initiated. These studies are centered upon the number of transfer ribonucleic acids that are specific for a certain amino acid and upon the rare nucleotide (or modified base) content of the plant transfer ribonucleic acids. Other studies are designed to determine whether the plant transfer ribonucleic acids will accept amino acids carried by the amino acid-activating enzymes from yeast. The long-term objective of these studies is to develop an understanding of the biochemical controls over the nutritional quality of plant proteins. (SWC 12-aA4)

2. The biosynthesis of amino acids in plants. Plant proteins are the source of the essential amino acids needed in the diet of nonruminant animals, and they also contribute an important part of the amino acids required by humans. A serious deficiency of plant proteins for these purposes is due to the relatively low plant contents of the sulfur amino acids, methionine and cystine. Studies of the synthesis and metabolism of sulfur amino acids in plants have been continued at the U. S. Plant, Soil, and Nutrition Laboratory, in cooperation with Cornell University and the Sulphur Research Institute, in hopes of developing ways of increasing the levels of these compounds in plant proteins. In the early stages of this project, it was found that the methyl ( $-CH_3$ ) group of S-methylcysteine could be transferred to methionine, and it seemed possible that S-methylcysteine was a close precursor of methionine. More recent

detailed experiments have revealed that the methyl group is not transferred directly to methionine by transmethylation, but is instead degraded to formaldehyde, and the formaldehyde is then incorporated into methionine.

Another study of amino acid metabolism in plants has been concerned with the effect of wilting or water stress upon the free amino acids in plants. In the early phases of this study, it was shown that water deficiency in leaves results in an increase in the content of the amino acid proline in the leaves. Experiments using radioactive precursor compounds showed that this increase in proline comes from glutamine via glutamic semialdehyde. The primary effect of wilting is to increase the conversion of glutamic acid to glutamic semialdehyde, thus providing an increased level of the immediate precursor of the proline. Continuing studies are being directed toward the mechanism whereby water deficiency works to increase the conversion of glutamic acid to glutamic semialdehyde.

One of the enzymes that degrades the amino acid arginine in plants has been purified and partially characterized. This enzyme is called arginine desimidase and acts in the conversion of arginine to ammonia and citrulline. It was isolated from the algae "Chlorella." The enzyme was purified about twenty-fold, and its stability, pH optimum, substrate specificity, and cofactor requirements were determined. (SWC 12-aA7)

#### E. Trace Element Functions and Interactions in Animal Nutrition

1. Interrelationships of trace minerals and vitamins. Studies of possible relationships between copper and vitamin B<sub>6</sub>. Studies of a possible relationship between Cu and pyridoxine in the nutrition of the animal are now in progress in cooperation with the Biochemistry Department at Cornell. Experiments are being conducted using Cu-deficient and Cu-adequate rats. As a part of the first experiment, two groups of rats--one fed a Cu-deficient, the other a Cu-adequate diet--were pair-fed. Toward the end of the experimental period, urine collections were made for each rat before and after an intraperitoneal injection of the amino acid, tryptophan. The tryptophan load test is one means of examining the pyridoxine status of the animal. Tentative results appear to corroborate the hypothesis that Cu is associated with some of the pyridoxal enzymes concerned with the metabolism of tryptophan. The urine of the Cu-deficient rats contained 37 percent more kynurenic acid than did the urine of the Cu-adequate rats. This study is continuing and will be extended to include comparisons of the levels of selected enzymes in several different animal tissues. (SWC 12-aA3)

2. The mechanisms involved in the absorption of copper from the intestine. Investigations of the mechanism of the zinc-copper antagonism have been continued. Results from these recent experiments provided good evidence that Zn interferes with Cu absorption by a direct interference that is mediated in either the lumen or the wall of the gut.

Some further work has been done regarding the effect of Cu deficiency on increased Cu absorption in rats. In more recent studies, the Cu concentrations in the lumen of the guts of Cu-deficient and Cu-adequate rats were equalized, and the deficient rats apparently absorbed more Cu under these conditions as well. This would indicate that the increased uptake of copper-64 by Cu-deficient rats cannot be explained on the basis of less dilution by endogenous intestinal Cu. These results are additionally supported from experiments using a whole-body counter, i.e., it was found that Cu-deficient rats retain more of an oral dose of copper-64 than do Cu-adequate rats. The mechanisms by which Cu-deficient rats utilize Cu more efficiently are not known.

Work on the effect of dose size on Cu absorption has continued and been expanded to a wider range of doses. These later experiments confirmed the earlier observations that as dose size increased, there was an initial drop in the percentage of the dose of radioisotope that was absorbed.

The effects of high levels of ascorbic acid (vitamin C) on Cu metabolism have also been investigated. This problem has been studied using both the in vivo, ligated loop technique and a whole-body counting technique. The results indicate that high levels of ascorbic acid depress the intestinal absorption of Cu. (SWC 12-aA3)

3. Studies on the role of manganese in the synthesis of mucopolysaccharides in chicks. Experiments have been performed in an attempt to define the role of Mn in the synthesis of chondroitin sulfate. Results provide a biochemical explanation for the leg weakness associated with Mn deficiency. The animals are unable to synthesize chondroitin sulfate in quantities sufficient to maintain the structural rigidity of cartilage and bone. At the present time, little is known about the exact mechanism of action of Mn in these enzymatic reactions. However, these enzymes do not appear to be metallo-enzymes, since Mn can be easily removed from the system. It is interesting to note that these reactions that require Mn utilize UDP-derivatives of sugars in the galactose configuration as substrates. (SWC 12-aA8)

4. Effects of manganese and zinc upon performance and reproduction. In an attempt to assess the effects of a manganese deficiency on the performance of rats, rats fed a dried whole milk diet with and without Mn were tested in a water or a dry maze. However, when the results of these two tests were compared with the results for rats purchased from a supplier, both experimental groups tested below the supplier-raised animals in the water maze. Since the possibility existed that the poorer performance of the experimental groups was a result of the milk diet, an experiment was done with weanling rats to test the effect of various purified diets on performance in the two mazes. The diets used were the whole milk diet, a skim milk diet, a casein diet, a soy diet, and a commercial pellet diet.

In this experiment, there was no difference between any of the groups in the water maze, but the rats on the whole-milk diet did poorer than the others in the dry maze.

Since the diet appeared to affect the performance of weanling rats, an experiment was done to determine if the effects would be greater if the dams were on the diet during gestation and the young, therefore, on the diet before weaning. Data from this experiment are not complete, but in the course of the experiment, it was noted that parturition was much more difficult for the females on the soy diet, with several dying in labor or shortly after, than for the other females. Addition of zinc to the diet apparently corrected the difficulty. Further experiments are being conducted on the possible role of Zn in parturition. (SWC 12-aA3)

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Effect of Soils Upon the Nutritional Quality of Plants

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#### Trace Element Functions and Interactions in Animal Nutrition

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Line Project Check List -- Reporting Year April 1, 1966 to March 31, 1967

				Line Project Inc. in	
Work and				Summary of:	
Line Project				Progress : Area and	
Number	Work and Line Project Titles	During Past Year	(Yes-No)	Subheading	
SWC 1	:Sedimentation processes in relation to	:	:		
	: watershed development and protection.	:	:		
SWC 1-a1	:Development and evaluation of means and	:Buffalo, N.Y.	: Yes	:1-D-1	
	: measures for channel stabilization in	:University Park, Pa.	:		
	: the Northeast.	:	:		
SWC 1-19(a2)(C)	:Analysis and synthesis of bedload	:University Park, Pa.	: No		
	: formulas.	:	:		
SWC 1-b1	:Sediment production, yield and delivery	:Oxford, Miss.	: Yes	:1-A-1, 3, 4	
	: ratio in relation to climatic factors	:Holly Springs, Miss.	:		
	: and watershed characteristics in	:Athens, Ga.	:		
	: the Southern Branch and at the	:Cartersville, Ga.	:		
	: U.S. Sedimentation Laboratory.	:Watkinsville, Ga.	:		
SWC 1-b2	:Investigations of the nature and	:Oxford, Miss.	: Yes	:1-B, E	
	: processes of reservoir sedimentation	:	:		
	: in the Southern Branch and at the	:	:		
	: U.S. Sedimentation Laboratory.	:	:		
SWC 1-b3	:Mechanics of sediment entrainment,	:Oxford, Miss.	: Yes	:1-C-1, 2	
	: transportation and deposition in	:	:		
	: natural and artificial channels in	:	:		
	: the Southern Branch and at the	:	:		
	: U.S. Sedimentation Laboratory.	:	:		
SWC 1-b-4	:Investigations of stream channel	:Oxford, Miss.	: Yes	:1-A-5, F	
	: morphology in the Southern Branch and	:Watkinsville, Ga.	:		
	: at the U.S. Sedimentation Laboratory.	:Ft. Lauderdale, Fla.	:		
SWC 1-b-5	:Development of structural measures for	:Oxford, Miss.	: Yes	:1-D-2	
	: sediment control and for stream	:	:		
	: channel stabilization in the Southern	:	:		
	: Branch and at the U.S. Sedimentation	:	:		
	: Laboratory.	:	:		
SWC 1-7(c1)(R)	:Sediment sources and yields in	:Columbia, Mo.	: Yes	:1-A-1	
	: agricultural watersheds in Corn Belt	:Council Bluffs, Iowa	:		
	: States.	:Coshocton, Ohio	:		
SWC 1-17(c3)	:Reservoir sedimentation studies in	:Columbia, Mo.	: Yes	:1-B	
	: Corn Belt States.	:	:		
SWC 1-d2	:Sediment production, yield and	:Hastings, Nebr.	: Yes	:1-A-2	
	: delivery ratio in relation to cli-	:Rosemont, Nebr.	:		
	: matic, geologic, and watershed char-	:Newell, S. Dak.	:		
	: acteristics of the Northern Plains.	:	:		
SWC 1-18(d3)	:Factors influencing the stability and	:Hastings, Nebr.	: Yes	:1-B, D	
	: regime of channels in agricultural	:Ft. Collins, Colo.	:		
	: watersheds of the Northern Plains.	:	:		
SWC 1-e1	:Sediment production, movement, and	:Chickasha, Okla.	: Yes	:1-A-2, 4	
	: deposition in agricultural watersheds	:Riesel, Tex.	:		
	: in the Southern Great Plains.	:Sonora, Tex.	:		
SWC 1-e2	:Stream channel stabilization and	:Chickasha, Okla.	: No		
	: sediment control works in channels	:Stillwater, Okla.	:		
	: in the Southern Great Plains.	:	:		
SWC 1-f1	:Sediment movement and deposition on	:Boise, Idaho	: No		
	: upstream agricultural watersheds of	:	:		
	: the Pacific Northwest.	:	:		
SWC 1-g1	:Sediment yields of agricultural	:Tucson, Ariz.	: Yes	:1-A-1, 2,	
	: watersheds in the Southwest.	:Tombstone, Ariz.	:		
	:	:Safford, Ariz.	:		
	:	:Albuquerque, N. Mex.	:		
	:	:Santa Rosa, N. Mex.	:		
	:	:Camarillo, Calif.	:		
	:	:Moorpark, Calif.	:		
	:	:	:		



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Work and Line Project Number	Work and Line Project Titles	During Past Year	Line Project Inc. in Summary of: Progress : Area and (Yes-No) : Subheading
SWC 2	:Hydrology of agricultural watersheds : and associated aquifers in relation : to treatment for flood prevention and : multiple use of water resources.	:Beltsville, Maryland	: Yes :2-H
SWC 2-a1	:The relation of rain, snow, and frozen : soils to the hydrology of agricultural : watersheds in the Northeast.	:Danville, Vt. :Blacksburg, Va. :Beltsville, Md.	: Yes :2-A-1, F-2
SWC 2-a2	:Water yield in relation to climatic : and watershed characteristics of land : resources areas in the Northeast.	:University Park, Pa. :Danville, Vt. :Blacksburg, Va.	: Yes :2-B-1, 2, 4, : E-1, G-1
SWC 2-a3	:Storm runoff and floodflows in relation : to climatic and watershed character- : istics of land resource areas in the : Northeast.	:Beltsville, Md. :University Park, Pa. :Danville, Vt. :Blacksburg, Va.	: Yes :2-B-4, F-2, : G-1
SWC 2-aD1	:Analytical hydrography in watershed : engineering.	:Beltsville, Md.	: Yes :2-A-1, B-1, 4, : F-1, 2, G-1, 2
*SWC 2-28(aD2)(C)	:Laboratory testing of hydraulic formu- : lations for open channel flow.	:Beltsville, Md.	: No :
SWC 2-b1	:Relation of climatic and watershed : factors to runoff rates and volume : yields in the Southern Branch.	:Ft. Lauderdale, Fla. :Oxford, Miss. :Athens, Ga.	: Yes :2-E-2
SWC 2-b2	:Precipitation characteristics influenc- : ing runoff from agricultural water- : sheds in the Southern Branch.	:Ft. Lauderdale, Fla. :Oxford, Miss. :Athens, Ga.	: Yes :2-A-2
SWC 2-b3	:Runoff production by unit source area : agricultural watersheds in the South.	:Oxford, Miss. :Holly Springs, Miss. :Watkinsville, Ga.	: Yes :2-B-3
SWC 2-b4	:Subsurface and ground water accretion, : depletion, movement and contribution : to streamflow for agricultural water- : sheds in the Southern Branch.	:Oxford, Miss. :Ft. Lauderdale, Fla. :Athens, Ga.	: Yes :2-C-1
**SWC 2-29(b5)(C)	:Studies to determine interrelationships : between watershed factors that affect : runoff rates and volume yields in the : Southern Coastal Plain Land Resource : Area.	:Athens, Ga.	: No :
SWC 2-c1	:Precipitation and snowmelt character- : istics influencing runoff from : agricultural watersheds in Corn Belt : States.	:Coshocton, Ohio	: Yes :2-A-1
SWC 2-c2	:Runoff production by unit source area : agricultural watersheds in Corn Belt : States.	:Coshocton, Ohio	: Yes :2-D-1, E-3
SWC 2-c3	:Relation of climatic and watershed : factors to storm runoff in Corn Belt : States.	:Coshocton, Ohio :Columbia, Mo. :Council Bluffs, Iowa :Fennimore, Wisc. :Madison, Wisc.	: Yes :2-F-1
SWC 2-c4	:Relation of climatic and watershed : physiographic and cultural factors : to water yield in Corn Belt States.	:Coshocton, Ohio :Columbia, Mo. :Council Bluffs, Iowa :Fennimore, Wisc. :Madison, Wisc.	: Yes :2-B-4
	: : Approved April 6, 1966 : **Approved May 20, 1966 :		

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Work and Line Project Number	Work and Line Project Titles	During Past Year	Line Project Inc. in Summary of: Progress : Area and (Yes-No) : Subheading
SWC 2-c5	:Aquifer and subsurface relationships : in the hydrology of upstream agri- : cultural watersheds in Corn Belt : States.	:Coshocton, Ohio :Columbia, Mo. :Fennimore, Wisc. :Madison, Wisc.	: Yes :2-D, E-1, 2 : : :
SWC 2-27(c6)	:Soil moisture regimes of agricultural : watersheds in Corn Belt States. : :	:Coshocton, Ohio :Columbia, Mo. :Council Bluffs, Iowa :Madison, Wisc.	: Yes :2-B-2 : : :
SWC 2-d1	:Water yield as related to integrated : climatic and watershed characteristics : in the Northern Plains. : :	:Hastings, Nebr. :Rosemont, Nebr. :Newell, S. Dak. :Cottonwood, S. Dak.	: Yes :2-B-3 : : :
SWC 2-d2	:Storm runoff and floods as related to : integrated climatic and watershed : characteristics in the Northern : Plains. : :	:Hastings, Nebr. :Rosemont, Nebr. :Newell, S. Dak. :Cottonwood, S. Dak. :Akron, Colo.	: Yes :2-A-1 : : : :
SWC 2-e1	:Precipitation characteristics influ- : encing runoff from agricultural : watersheds in the Southern Plains. : :	:Chickasha, Okla. :Riesel, Tex. :Sonora, Tex.	: Yes :2-A-1 : :
SWC 2-e2	:Runoff production by unit source areas : in the Southern Plains. : :	:Stillwater, Okla. :Cherokee, Okla. :Chickasha, Okla. :Riesel, Tex.	: Yes :2-B-2, G-1, 2 : : :
SWC 2-e3	:Relation of climatic and watershed : factors to storm runoff in the : Southern Plains. : :	:Sonora, Tex. :Chickasha, Okla. :Stillwater, Okla. :Riesel, Tex.	: No : : : :
SWC 2-e4	:Relation of climatic and watershed : physiographic and cultural factors : to water yield in the Southern : Plains. : :	:Sonora, Tex. :Chickasha, Okla. :Stillwater, Okla. :Riesel, Tex. :Sonora, Tex.	: Yes :2-C-2, D-2 : : : :
SWC 2-f1	:Aquifer-streamflow interrelationships : in upstream agricultural watersheds : of the Pacific Northwest. : :	:Boise, Idaho : : :	: Yes :2-C-1 : : :
SWC 2-f2	:Precipitation characteristics influ- : encing hydrologic performance of : agricultural watersheds in the : Pacific Northwest. : :	:Boise, Idaho :Moscow, Idaho : :	: Yes :2-A-1, 3 : : :
SWC 2-f3	:Runoff and sediment movement on unit : source watersheds of the Pacific : Northwest as influenced by climate, : soils, vegetation, and topography. : :	:Boise, Idaho :Moscow, Idaho : :	: Yes :2-A-4, 5, : F-1 : :
SWC 2-f4	:Water accumulation, flood-wave movement : and water yield from complex water- : sheds of the Pacific Northwest. : :	:Boise, Idaho :Moscow, Idaho : :	: Yes :2-B-1, 3, 4, : E-2 : :
SWC 2-g1	:Precipitation characteristics influ- : encing the hydrology of agricultural : watersheds in the Southwest. : : : : : : : : : :	:Tucson, Ariz. :Tombstone, Ariz. :Safford, Ariz. :Albuquerque, N. Mex. :Santa Rosa, N. Mex. :Lompoc, Calif. :Tehachapi, Calif. : : : : :	: Yes :2-A1, 3 : : : : : : : : : :

Work and Line Project Number	Work and Line Project Titles	During Past Year	Line Project Inc. in Summary of: Progress : Area and (Yes-No) : Subheading
SWC 2-g2	:Relation of integrated climatic, watershed, and cultural factors to storm runoff from agricultural watersheds in the Southwest.	:Tucson, Ariz. :Tombstone, Ariz. :Safford, Ariz. :Albuquerque, N. Mex. :Santa Rosa, N. Mex. :Lompoc, Calif :Logan, Utah	: Yes :2-B-1, 3, : F-1
SWC 2-g3	:Relation of integrated climatic, watershed, and cultural factors to water yields from agricultural watersheds in the Southwest.	:Tucson, Ariz. :Tombstone, Ariz. :Safford, Ariz. :Albuquerque, N. Mex. :Santa Rosa, N. Mex. :Lompoc, Calif. :Riverside, Calif. :Logan, Utah	: Yes :2-D-2

[illegible]

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Work & Line	Project	Number	Work and Line Project Titles	Work Locations	During Past Year	Line Project Incl. in	Summary of:	Progress	Area and
						(Yes-No)			Subheading
SWC 5			Irrigation principles, requirements, practices, and facilities for efficient use of water on farms						
SWC 5-a1			Irrigation practices and factors affecting the water requirement of crops in different land resource areas of the Northeast	New Brunswick, N. J.		No			
SWC 5-b1			Irrigation requirements, practices and methods of application for efficient production of crops in the Southeast	Thorsby, Ala. Ft. Lauderdale, Fla. Watkinsville, Ga. State College, Miss. Florence, S. Car.		Yes			5-A-3, 4, B-3
SWC 5-c1			Improvement in performance and design of irrigation systems in the Corn Belt			No			
SWC 5-d1			Irrigation practices, requirements and design criteria for efficient use of water and sustained crop production in the Northern Plains	Akron, Colo. Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Hawaiian Islands Lincoln, Nebr. Mandan, N. Dak. Fontenelle, Wyo.		Yes			5-A-3, B-2, C-2
SWC 5-5(e1) (Rev.)			Irrigation water management for efficient water use in the Southern Plains	Bushland, Tex. Weslaco, Tex.		Yes			5-A-3, 4
SWC 5-f1			Irrigation requirements, principles, and practices for efficient use of water in the Pacific Northwest	Twin Falls, Ida. Prosser, Wash.		Yes			5-A-1, 2, 3, 4, B-1, 6-C
SWC 5-f2			Surface and sprinkler design and operation principles and facilities for efficient water use in the Pacific Northwest	Twin Falls, Ida.		Yes			4-B-3, 5-B-1, C-1, 2
SWC 5-8(g1) (Rev.)			Improved irrigation water application systems in the Southwest	Riverside, Calif. Logan, Utah		Yes			5-B-1, 3
SWC 5-9(g2) (Rev.)			Irrigation requirements of forage and cultivated crops in the Southwest	Lompoc, Calif. Riverside, Calif. Reno, Nev.		Yes			5-A-1
A10-SWC-5			Performance and scientific design of sprinklers used for irrigation	Haifa, Israel		No			
A10-SWC-11			Further studies on the Blaney and Criddle formula V-KF to ascertain the consumptive use of water by plants by means of analysis of climatological data	Rehovot, Israel		No			
A10-SWC-19			Crop, soil, and water use effects of low intensity sprinkler irrigation application	Rehovot, Israel		Yes			5-B-2
A10-SWC-29			Studies on the influence of plant and environmental factors on photosynthesis, stomatal aperture and transpiration	Rehovot, Israel		Yes			5-A-2

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of: Progress : Area and (Yes-No) : Subheading
SWC 6	: Drainage principles, requirements, : practices, and facilities for : protection of crops and soils	:	:
SWC 6-a1	: Development and evaluation of surface : and subsurface drainage practices in : different land resource areas of the : Northeast	: Norfolk, Va. : Burlington, Vt. :	: Yes : 6-D-1, 2, 3 :
SWC 6-b1	: Drainage requirements of crops in the : South	: Ft. Lauderdale, Fla. : Watkinsville, Ga. : Baton Rouge, La. : Raleigh, N. Car. : Florence, S. Car.	: Yes : 6-D-1, 3 :
SWC 6-b2	: Design, installation, and maintenance : of surface and subsurface drainage : systems with or without land forming : and conditioning in the South	: Fleming, Ga. : Baton Rouge, La. : Florence, S. Car. :	: Yes : 6-A-1, 2, : D-2
SWC 6-c1	: Improvement and modernization of : surface and subsurface drainage : practices and facilities in the Corn : Belt	: Columbus, Ohio : Morris, Minn. :	: Yes : 6-B-1, 2, : D-2
SWC 6-d1	: Drainage facilities, methods, and : design criteria for protection and : improvement of agricultural crops and : soils in the Northern Plains	: Ft. Collins, Colo. : Grand Junction, Colo. : Grand Forks, N. Dak. :	: Yes : 6-B-1, D-1 :
SWC 6-12(e3)	: Improved drainage systems design, : materials, installation techniques : and drainage requirements of crops : in the Southern Plains	: Weslaco, Tex. :	: Yes : 6-B-1 :
SWC 6-g1	: Basic drainage principles in the : Southwest	: Logan, Utah :	: No : :
SWC 6-g2	: Drainage facilities, methods and : evaluation for irrigated lands in the : Southwest	: Brawley, Calif. : Reno, Nev. : Columbus, Ohio : Logan, Utah	: Yes : 6-B-3, C, : D-2
SWC 6-g3	: Drainage and aeration requirements of : crops on irrigated lands in the : Southwest	: Reno, Nev. :	: No : :
SWC 6-gF1	: Principles of drainage as related to : salt-affected soils	: Riverside, Calif. :	: Yes : 6-C :

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Area and Subheading
SWC 7	: Saline, sodic, and related soils : problems, and quality of irrigation : waters and their relation to plant : growth processes			
SWC 7-a1	: Investigations of the effects of using : saline and industrial waste waters on : the yield and quality of plants, and : on physical and chemical character- : istics of soils	: Norfolk, Va.	: Yes	: 7-B-2, D
SWC 7-b1	: The effect of brackish water on plants : and soils in the South		: No	
SWC 7-d1	: Improvement and management of saline : and sodic soils of the Northern Plains	: Grand Forks, N. Dak. : Mandan, N. Dak. : Newell, S. Dak.	: Yes	: 7-E
SWC 7-e1	: Saline and sodic soils and irrigation : water quality problems in the Rio : Grande River Basin	: Weslaco, Tex	: Yes	: 7-F
SWC 7-18(e2)	: Spectral reconnaissance for diagnosis : of soil and water management problems	: Weslaco, Tex.	: Yes	: 7-F
SWC 7-f1	: Soil and water management practice for : the control or alleviation of saline : and sodic soil problems in the Pacific : Northwest	: Twin Falls, Ida. : Ontario, Ore.	: Yes	: 7-E
SWC 7-g1	: Effect of leaching, amendments, water : quality, and soil and crop management : practices on the soluble salt and : adsorbed cation status of salt- : affected southwestern soils	: Brawley, Calif. : Riverside, Calif. : Reno, Nev.	: Yes	: 7-D, E
SWC 7-gF1	: Mechanisms of reactions between : dissolved and adsorbed constituents : of salt-affected soils	: Riverside, Calif.	: Yes	: 7-A-1
SWC 7-gF2	: Structure, organic matter, and micro- : bial relations in salt-affected soils	: Riverside, Calif.	: Yes	: 7-A-2
SWC 7-gF3	: Methods for the diagnosis and study of : salinity in soils and water	: Riverside, Calif.	: Yes	: 7-A-3
SWC 7-gF4	: Soil physical and chemical conditions : in relation to plant growth on salt- : affected soils	: Riverside, Calif.	: Yes	: 7-A-4
SWC 7-gF5	: Tolerance of economic plants to : salinity and exchangeable sodium	: Riverside, Calif.	: Yes	: 7-B-1
SWC 7-gF6	: Plant-water relationships under saline, : drought, or high exchangeable-sodium : conditions	: Riverside, Calif.	: Yes	: 7-A-4
SWC 7-gF7	: Effects of salinity and exchangeable- : cation status on absorption, distri- : bution and metabolic effectiveness of : ions in plants	: Riverside, Calif.	: Yes	: 7-B-3
SWC 7-gF8	: Effects on plants of specific ions : associated with salinity or : exchangeable sodium	: Riverside, Calif.	: Yes	: 7-B-4
SWC 7-gF9	: Influence of climatic and edaphic : factors on plant response to salinity : and exchangeable sodium	: Riverside, Calif.	: Yes	: 7-B-1
SWC 7-gF10	: Chemical composition of irrigation : waters in relation to their : suitability for use	: Riverside, Calif.	: Yes	: 7-C

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Work & Line Project Number	:	:	:	Line Project Incl. in
	:	:	:	Summary of:
	:	Work Locations	:	Progress : Area and
	:	During Past Year	:	(Yes-No) : Subheading
SWC 7-gF11	: Principles of salinity control,	: Riverside, Calif.	:	Yes : 7-D
	: including the amelioration of salt-	:	:	:
	: affected soils by leaching and the	:	:	:
	: use of amendments	:	:	:
A10-SWC-7	: The response of plants to changing	: Jerusalem, Israel	:	Yes : 7-B-5
	: salinity	:	:	:
A10-SWC-24	: Development of methods for measuring	: Haifa, Israel	:	No : :
	: partial vapor pressure in soil water	:	:	:
A10-SWC-30	: Physiological adaptation of plants to	: Beersheva, Israel	:	Yes : 7-B-5
	: moisture and osmotic stresses with	:	:	:
	: respect to salt accumulation	:	:	:
A10-SWC-31	: Theoretical and experimental investi-	: Jerusalem, Israel	:	Yes : 7-B-5
	: gations of the mechanism of flow of	:	:	:
	: water and solutes in plant roots	:	:	:
	:	:	:	:

Work & Line Project Number	:	Work and Line Project Titles	:	Work Locations During Past Year	:	Line Project Incl. in Summary of:
	:		:		:	Progress : Area and Subheading
	:		:		:	(Yes-No)
SWC 8	:	:Water and wind erosion control : principles, practices, systems, and : prediction methods for conservation : of crop and rangelands	:		:	
SWC 8-a1	:	:Determination and evaluation of factors: : affecting water runoff and erosion in : the different land resource areas of : the Northeast as related to soil and : water conservation practices	:	:Orono, Me. :Presque Isle, Me. :Ithaca, N.Y.	:	: Yes : :
SWC 8-b1	:	:Effects of soil, topography, climate, : cropping and management procedures on : runoff and erosion and on the predic- : tion of soil losses in the South	:	:Tifton, Ga. :Watkinsville, Ga. :Holly Springs, Miss.: :Rio Piedras, P.R.	:	: Yes : : :
SWC 8-b2	:	:Development of supporting practices, : systems, techniques and devices for : runoff and erosion control in the : South	:	:Watkinsville, Ga. : : :	:	: No : : :
SWC 8-c1	:	:Basic principles and mechanics of : rainfall, runoff, soil movement and : loss in the Corn Belt	:	:Urbana, Ill. :Lafayette, Ind. :Morris, Minn.	:	: Yes : :
SWC 8-c2	:	:Evaluation of climatic, topographic, : soil and crop management and erosion : control in the Corn Belt	:	:Lafayette, Ind. :Ames, Ia. :Morris, Minn. :Columbia, Mo.	:	: Yes : : :
SWC 8-c3	:	:Development and refinement of methods : for predicting field runoff and soil : loss	:	:Madison, S. Dak. :LaFayette, Ind. :Morris, Minn. :St. Paul, Minn.	:	: Yes : : :
SWC 8-c4	:	:Development of supporting runoff and : erosion control practices and systems : in the Corn Belt	:	:Morris, Minn. :Columbia, Mo. :Madison, S. Dak.	:	: Yes : :
SWC 8-8(d1) (Rev.)	:	:Water and wind erosion and its control : on irrigated and nonirrigated lands : in the Northern Plains	:	:Sidney, Mont. :Lincoln, Nebr. :Rosemont, Nebr. :St. Paul, Nebr. :Mandan, N. Dak.	:	: Yes : : : :
SWC 8-e1	:	:Wind erosion control in the Southern : Plains	:	:Manhattan, Kans. :Big Spring, Tex. :Bushland, Tex.	:	: Yes : :
SWC 8-10(e2) (Rev.)	:	:Mechanics and principles of water : erosion and their application for : erosion control in the Southern Plains	:	:Manhattan, Kans. :Cherokee, Okla. :Chickasha, Okla. :Big Spring, Tex. :Temple, Tex.	:	: Yes : : : :
SWC 8-f1	:	:Erosion and runoff control practices : and systems to conserve soil and water : resources in the Pacific Northwest	:	:St. Anthony, Ida. :Pendleton, Ore. :Pullman, Wash.	:	: Yes : :
SWC 8-f2	:	:Fundamental aspects of water erosion : in the Pacific Northwest	:	:Pullman, Wash. : : : : : :	:	: No : : : : : :

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				Summary of:	
			Work Locations	Progress	Area and
		Work and Line Project Titles	During Past Year	(Yes-No)	Subheading
SWC 9	:	Moisture conservation for the effi-	:	:	:
	:	cient and effective use of precipi-	:	:	:
	:	tation on crops and range lands.	:	:	:
SWC 9-1(c1) (R)	:	Development of soil management	Morris, Minn.	Yes	9-A-1; C-1, 3
	:	systems for efficient use of soil	Madison, S. Dak.	:	:
	:	moisture in the Corn Belt region.	Urbana, Ill.	:	:
SWC 9-d1	:	Improved water conservation and use	Akron, Colo.	Yes	9-A-3, 4, 5;
	:	on nonirrigated lands of the	Ft. Collins, Colo.	:	B-1, 2, 3;
	:	Northern Plains	Bozeman, Mont.	:	C-1, 2, 4
	:		Sidney, Mont.	:	:
	:		Lincoln, Nebr.	:	:
	:		North Platte, Nebr.	:	:
	:		Scotts Bluff, Nebr.	:	:
	:		Mandan, N. Dak.	:	:
	:		Newell, S. Dak.	:	:
	:		Laramie, Wyo.	:	:
SWC 9-el	:	Conservation and efficient use of	Bushland, Texas	Yes	9-A-1, 3; B-2;
	:	precipitation in the Southern Great	Temple-Riesel, Tex.	:	C-4, 5
	:	Plains	:	:	:
SWC 9-fl	:	Moisture conservation principles	St. Anthony, Idaho	Yes	9-A-2
	:	and practices in the Southern	Twin Falls, Idaho	:	:
	:	Great Plains	Pendleton, Oregon	:	:
SWC 9-gl	:	Perfecting cropping sequences, land	Riverside, Calif.	Yes	9-A-3; C-4
	:	and water management systems, and	:	:	:
	:	cultural practices to conserve and	:	:	:
	:	efficiently utilize precipitation.	:	:	:
A10-SWC-32	:	Soil water evaporation and means of	Volcani Institute	Yes	9-B-3
	:	minimizing it.	Agr. Res., Nat'l.	:	:
	:		& Univ. Inst. of	:	:
	:		Agriculture,	:	:
	:		Rehovot, Israel	:	:
	:		:	:	:
	:		:	:	:

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. In Summary of: Progress : Area and Subheading
SWC 10	Soil properties, processes and management in relation to the conservation and efficient use of land and water resources.		
SWC 10-a1	Development of improved soil management and conservation practices on croplands in different land resource areas of the Northeast	Presque Isle, Me. Marcellus, N. Y. Marlboro, N. J. Blacksburg, Va. Morgantown, W. Va.	Yes : 10-B-2; C-2
SWC 10-a2	Development of improved soil management practices for grassland soils in different land resource areas of the Northeast.	University Park, Pa. Morgantown, W. Va.	Yes : 11-B-4
SWC 10-36(a3)	Fixation of atmospheric nitrogen by rhizobia.	Beltsville, Md.	Yes : 10-D-1
SWC 10-aB1	Fixation of ammonium ion in soils and its release to plants	Beltsville, Md.	No :
SWC 10-aB2	Biological transformations of nitrogen in soil, including biological interchange in the rhizosphere; nonsymbiotic fixation, gaseous losses, and accumulation of toxic products.	Beltsville, Md.	Yes : 10-A-2
SWC 10-aB3	Humus formation in soils and the interaction of organic compounds with clays.	Beltsville, Md.	No :
SWC 10-aB4	Evaluation of soil-pesticide complexes, including their decomposition.	Beltsville, Md.	No :
SWC 10-aB6	Genetic studies with nitrogen-fixing organisms.	Beltsville, Md.	No :
SWC 10-aB7	The relationship between the soil as the source of nutrients and the ion uptake process in the plant.	Beltsville, Md.	No :
SWC 10-aB8	Nutrient balance for plant growth as related to soil environment, plant species and variety, and the nature of added nutrient carriers.	Beltsville, Md.	Yes : 10-A-7; B-1
SWC 10-aB9	Development of spectrochemical methods and foliar diagnostic procedures for soil and plant investigations	Beltsville, Md.	No :
SWC 10-38 (aB11)	The effects of pesticides and other chemical contaminants on microbial processes in soils.	Beltsville, Md.	No :
SWC 10-39 (aB12)	The agricultural significance of certain transitional elements derived from pesticides and other agricultural chemicals.	Beltsville, Md.	No :
SWC 10-43 (aB13)	Development of analytical chemical methods in soil science research.	Beltsville, Md. Coshocton, Ohio	Yes : 10-A-4; B-2
SWC 10-b1	The lime requirements of red and yellow podzolic and related soils.	Auburn, Ala. Thorsby, Ala. Rio Piedras, P.Rico Florence, S. C.	Yes : 10-B-1
SWC 10-b2	The fertility requirement of exposed subsoils.	Puerto Rico	No :

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of:	Progress : Area and Subheading
SWC 10-b3	Fertilization for efficient crop production under intensive management	Watkinsville, Ga. Fleming, Ga. Puerto Rico	Yes	10-A-3, 7; C-3
SWC 10-b4	Developing improved cropping systems for soil conservation.	Watkinsville, Ga.	No	
SWC 10-b5	Crop residue management and tillage practices for soil conservation and efficient production in the South.	Puerto Rico Florence, S. C.	Yes	10-C-3; D-3
SWC 10-b6	Factors influencing crop rooting development and activity and means of increasing root development in the South.	Auburn, Ala. Thorsby, Ala. Florence, S. C.	Yes	10-B-1; C-1, 2
SWC 10-b7	Integration of improved practices for soil and water conservation in the South.	Watkinsville, Ga. Fleming, Ga.	Yes	10-C-3
SWC 10-c1	Moisture utilization in the Corn Belt as influenced by soil fertility level and management practices	Morris, Minn. Madison, S. Dak. Elsberry, Missouri	Yes	10-C-3
SWC 10-c2	Tillage practices and crop residue management for soil conservation and efficient production in the Corn Belt.	Morris, Minn. Elsberry, Missouri Ames, Iowa Madison, S. Dak.	Yes	10-A-2; 11-A-3; B-4
SWC 10-c3	Fundamental studies on the mechanism of soil structure formation in the Corn Belt.	St. Paul, Minn. Ames, Iowa	Yes	10-C-1
SWC 10-d1	Chemical reactions and availability of phosphates in Northern Plains soils as affected by fertilization, soil properties, and management.	Mandan, N. Dak. Grand Junction, Colo. Bozeman, Mont. Fort Collins, Colo. Huntley, Mont.	Yes	10-A-6
SWC 10-d2	Soil nitrogen transformations in relation to soil nitrogen maintenance and more efficient use of fertilizer nitrogen in the Northern Plains.	Huntley, Mont. Laramie, Wyo. Newell, S. Dak. Mandan, N. Dak. Fort Collins, Colo.	Yes	10-A-1, 4
SWC 10-d3	Fertilizer requirements and fertility status of Northern Plains soils for more efficient crop and forage production.	Akron, Colo. Fort Collins, Colo. Sidney, Mont. Mandan, N. Dak. Newell, S. Dak. Laramie, Wyo.	Yes	9-C-4; 10-A-3
SWC 10-d4	Improved soil management practices and systems for better conservation farming in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Huntley, Mont. Sidney, Mont. North Platte, Nebr. Bozeman, Mont. Mandan, N. Dak. Newell, S. Dak.	Yes	10-C-2, 3
SWC 10-d5	Principles and practices of stubble-mulch maintenance for soil and water conservation in the Northern Plains.	Akron, Colo. Bozeman, Mont. Huntley, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr. Mandan, N. Dak.	Yes	10-D-3

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SWC 10-40(d7)	Chemical, physical, and biological reactions of pesticides with soils affecting soil productivity and pesticide stability.	Fort Collins, Colo.	Yes	10-B-2
SWC 10-e1	Interrelationships between soil structure and plant growth.	Bushland, Texas Temple, Texas	Yes	10-A-2; C-1, 2
SWC 10-e2	Nutritional requirements for crop-land and rangeland in the Southern Great Plains.	Bushland, Texas Temple-Riesel, Tex. Weslaco, Texas Cherokee, Okla.	Yes	10-A-3, 5; C-2
SWC 10-f1	Soil management practices for conservation farming in the Pacific Northwest.	St. Anthony, Idaho Twin Falls, Idaho Prosser, Wash. Pullman, Wash.	Yes	10-A-3, 5; C-2
SWC 10-f2	Chemistry and availability of nutrient elements in soils of the Pacific Northwest.	Twin Falls, Idaho Corvallis, Oregon Pendleton, Oregon Prosser, Wash. Pullman, Wash.	Yes	10-A-2, 3, 5; 11-A-5
SWC 10-f3	Chemistry and effects of organic matter in soils of the Pacific Northwest.	Twin Falls, Idaho Corvallis, Oregon	Yes	10-A-2
SWC 10-f4	Microbial equilibria in soils of the Pacific Northwest.	Prosser, Wash.	Yes	10-D-1
SWC 10-g1	Principles of nutrient uptake and efficient fertilizer use in relation to moisture regime and irrigation practice, soil properties and crop nutrient requirements in the Southwest.	Brawley, Calif. Logan, Utah	Yes	10-A-2, 3
SWC 10-g2	Improvement of soil fertility, crop production and soil and water conservation through the use of fertilizers and soil amendments on rangeland and nonirrigated cropland in the Southwest.	Riverside, Calif.	No	
*SWC-0-0-1(AEC)	Soil chemistry and radioactive contamination in soils and plants	Beltsville, Md.	Yes	10-B-3
A7-SWC-7	A study of the soil algae of the rice fields and their contribution to the fertility of the soil.	U. of Allahabad, Allahabad, India	No	
A7-SWC-17	Iron and molybdenum as plant nutrients.	U. of Lucknow, Lucknow, India	No	
A7-SWC-23	Physiology and biochemistry of nitrogen fixation by blue-green algae. (Grant accepted 2-4-67)	Banaras Hindu U., Varanasi, India	No	
A7-SWC-29	Investigations on soil structure as influenced by organic matter with the help of microscopic and other techniques.	Indian Agr. Res. Insti., New Delhi, India	No	
A7-SWC-33	Ecological specialization of micro-organisms native to 'Usar' (alkaline) soils of India.	Lucknow U., Lucknow, India	Yes	10-D-3
A7-SWC-46	Survey and isolation of root nodule bacteria in Indian soils. (Grant accepted 11-1-66)	Indian Agr. Res. Insti., New Delhi, India	No	

\*This work is financially supported by the Atomic Energy Commission.

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				Summary of:	
			Work Locations	Progress :	Area and
		Work and Line Project Titles	During Past Year	(Yes-No) :	Subheading
A7-SWC-47	:	The influence of oxygen level and mechanical impedance as related to the plant growth and tillage requirements of flooded paddy.	Indian Insti. of Technology, Kharagpur, India	No	:
A10-SWC-1	:	Agricultural utilization of soils affected by salinity	Hebrew U., Rehovot, Israel	Yes	10-A-3
A10-SWC-8	:	Mode of occurrence of minor elements in sediments and soils: A fundamental study for the understanding of the behavior and distribution of minor elements in soils.	Hebrew U. of Jerusalem, Israel	No	:
A10-SWC-12	:	The determination of available microelements in calcareous soils.	Hebrew U., Rehovot, Israel	Yes	10-A-5
A10-SWC-15	:	Micro-heterometric methods for the quick and precise determination of trace elements in agriculture. (terminated September 1966)	Hebrew U. of Jerusalem, Israel	No	:
A10-SWC-22	:	Basic and applied research into efficiency of phosphate fertilization.	Technion-Israel Insti. of Tech., Haifa, Israel	Yes	10-A-6
A10-SWC-27	:	The movement of ions and salts through non-ideal porous media (as applied to problems of salt leaching and fertilizer distribution in soil profiles).	Technion-Israel Insti. of Tech., Haifa, Israel	No	:
A10-SWC-38	:	Fixation and availability of added phosphorus in soils as a function of bulk movement and diffusion.	Technion-Israel Insti. of Tech., Haifa, Israel	Yes	10-A-6
E21-SWC-2	:	Fundamental studies of reactions between mineral and organic components in soil.	College of Agr., Wroclaw, Poland	Yes	10-A-2
E21-SWC-10	:	Studies on genetics and taxonomy of Rhizobium.	M. Curie-Sklodowska U., Lublin, Poland	No	:
E21-SWC-11	:	The occurrence and behavior of trace elements in residual soils.	Insti. of Soil Sci. & Plant Cultivation, Pulawy, Poland	No	:
E25-SWC-7	:	Study of the retention of some substances of insecticidal and weed-controlling potential by the principal specific clay constituents, and relation of that retention to the specific surface area of the clay constituents, moisture and temperature.	U. of Granada, Granada, Spain	Yes	10-B-2
E30-SWC-1	:	Mineral nutrition and plant genetic variability in relation to transpiration, free and bound water in plants, and plant growth.	Insti. for Agr. Res., Novi Sad, Yugoslavia	No	:

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SWC 11	Soil, water, and plant relations as they affect use of land and water resources.			
SWC 11-a1	The energy budget at the earth's surface.	Ithaca, New York	Yes	11-B-2; C-1
SWC 11-b1	Modification of soil surface structure and crop geometry to beneficially influence climatic conditions in the South.	State College, Miss.	Yes	11-B-1
SWC 11-b2	Plant factors influencing transpiration in the South.	Watkinsville, Ga.	Yes	11-A-2; B-2, 3
SWC 11-c1	Soil moisture-plant growth relationships in the Corn Belt.	St. Paul, Minn. Urbana, Ill.	Yes	11-A-3; B-1, 2
SWC 11-c2	Climatic influence on water use and crop performance in the Corn Belt region.	Morris, Minn. Urbana, Ill.	Yes	11-B-1; C-2
SWC 11-c3	Soil moisture flow problems and solutions in the Corn Belt region.	Urbana, Ill. Madison, Wisc.	Yes	11-A-3
SWC 11-d1	Principles affecting soil structure stability and its effect on aeration intake, transmission, and storage of water on irrigated lands in the Northern Plains.	Brookings, S. Dak. Fort Collins, Colo. Grand Junction, Colo. Mandan, N. Dak.	Yes	11-A-5
SWC 11-e1	Understanding and improving soil-plant-atmospheric relationship for more efficient utilization of water.	Big Spring, Texas Bushland, Texas Temple-Riesel, Tex. Weslaco, Texas	Yes	11-A-4; B-2, 3
SWC 11-13(g1)	Physical processes affecting soil water and their relation to physiological functioning of plants.	Brawley, Calif. Reno, Nevada	No	
SWC 11-gF1	Physical properties and kinetics of change of the physical properties of water in soil-water systems.	Riverside, Calif.	Yes	11-A-1
SWC 11-gG1	Uptake and disposal of water by plants in an arid climate.	Phoenix, Arizona	Yes	11-B-1

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SWC 12	Nutrition of animals as affected by properties and characteristics of soils and plants.			
SWC 12-aA1	Studies of the effects of soil and geological conditions on the composition of forages and other crops in relation to nutritional problems in animals.	Ithaca, New York	Yes	12-B-1, 2, 3
SWC 12-aA2	Effect of environment, soil type, and soil management on the nutritive quality of crops as measured by animal growth, health, and reproduction.	Ithaca, New York Tifton, Ga. Davis, Calif. Reno, Nevada	Yes	12-A-1, 2
SWC 12-aA3(c)	Micronutrient elements of soils and plants in relation to certain endemic nutritional diseases of animals.	Ithaca, New York Corvallis, Oregon	Yes	12-E-1, 2, 4
SWC 12-aA4	The role of mineral elements, enzymes, nucleic acids, and other factors on the biosynthesis of proteins.	Ithaca, New York	Yes	12-D-1
SWC 12-aA5	Chemical reactions of micronutrient cations with clay minerals and plant extracts.	Ithaca, New York	Yes	12-C-1
SWC 12-aA6	Toxicities in food and forage plants with particular reference to nitrates and certain mineral elements.	Inactive	No	
SWC 12-aA7	Effect of plant nutrients and other mineral elements on the amino acid and protein content of food and forage plants.	Ithaca, New York	Yes	12-D-2
SWC 12-aA8	The role of mineral elements in the formation of the organic matrix of bone.	Ithaca, New York	Yes	12-E-3
A7-SWC-61	The regulation of ribonucleic acid and protein synthesis in developing plant cells.	Bose Insti., Calcutta, India	No	
A22-AH-2	White muscle disease of lambs	Ankara U., Ankara, Turkey	Yes	12-B-1

